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Pass et al.

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(54) **FOIL TRIM APPROACHES FOR FOIL-BASED METALLIZATION OF SOLAR CELLS**

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(22) Filed: **Sep. 18, 2014**

(51) **Int. Cl.**

H01L 31/02	(2006.01)
H01L 21/00	(2006.01)
H01L 31/0368	(2006.01)
H01L 31/028	(2006.01)
H01L 31/0304	(2006.01)
H01L 31/18	(2006.01)

(52) **U.S. Cl.**
CPC ***H01L 31/02021*** (2013.01); ***H01L 31/028*** (2013.01); ***H01L 31/0304*** (2013.01); ***H01L 31/03682*** (2013.01); ***H01L 31/18*** (2013.01)

(58) **Field of Classification Search**
CPC H01L 31/02021; H01L 31/028; H01L 31/0304; H01L 31/03682; H01L 31/18
See application file for complete search history.

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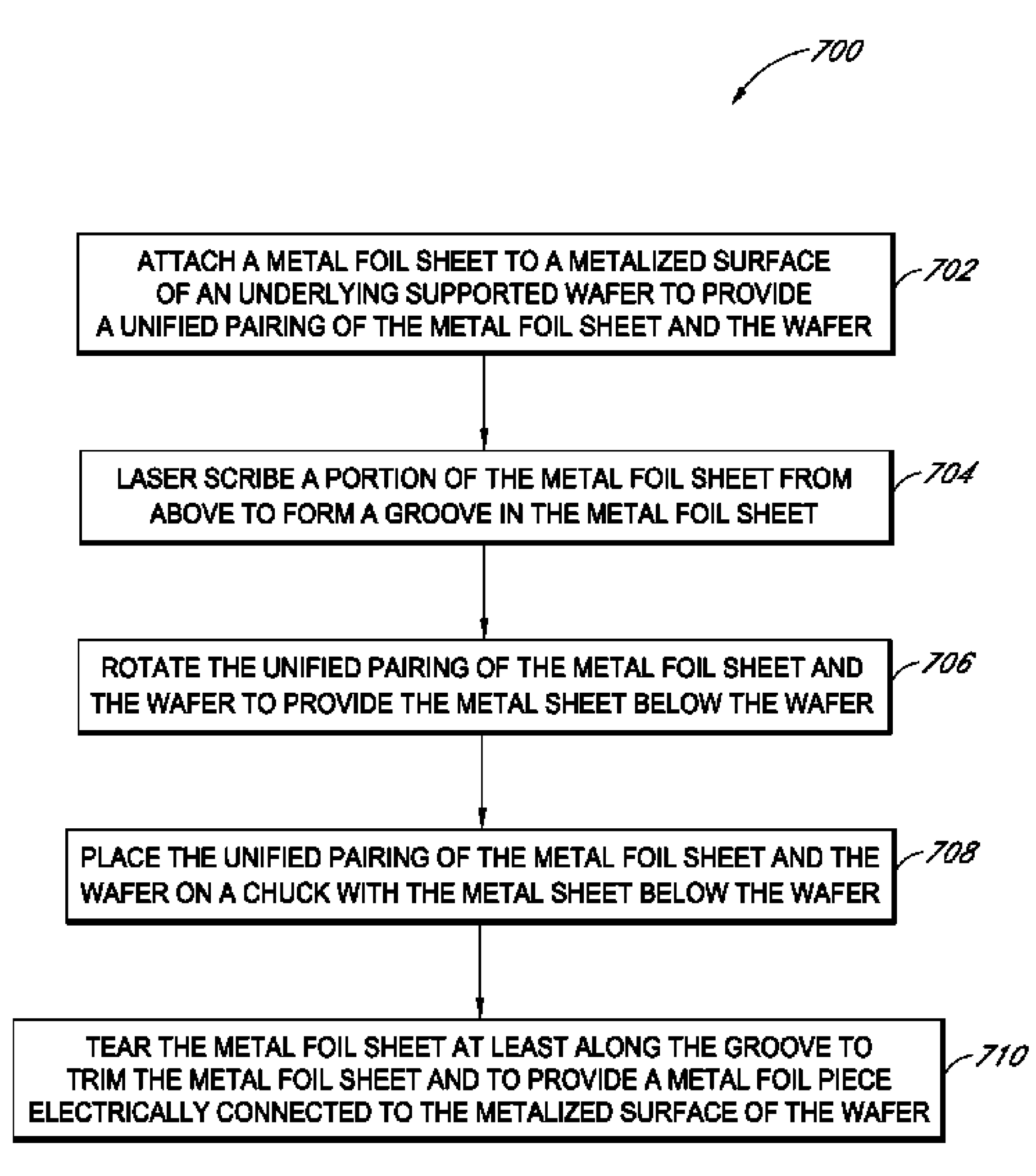
(57) **ABSTRACT**

Foil trim approaches for the foil-based metallization of solar cells and the resulting solar cells are described. For example, a method involves attaching a metal foil sheet to a metallized surface of an underlying supported wafer to provide a unified pairing of the metal foil sheet and the wafer. Subsequent to attaching the metal foil sheet, a portion of the metal foil sheet is laser scribed from above to form a groove in the metal foil sheet. Subsequent to laser scribing the metal foil sheet, the unified pairing of the metal foil sheet and the wafer is rotated to provide the metal sheet below the wafer. Subsequent to the rotating, the unified pairing of the metal foil sheet and the wafer is placed on a chuck with the metal sheet below the wafer. The metal foil sheet is torn at least along the groove to trim the metal foil sheet.

9 Claims, 16 Drawing Sheets



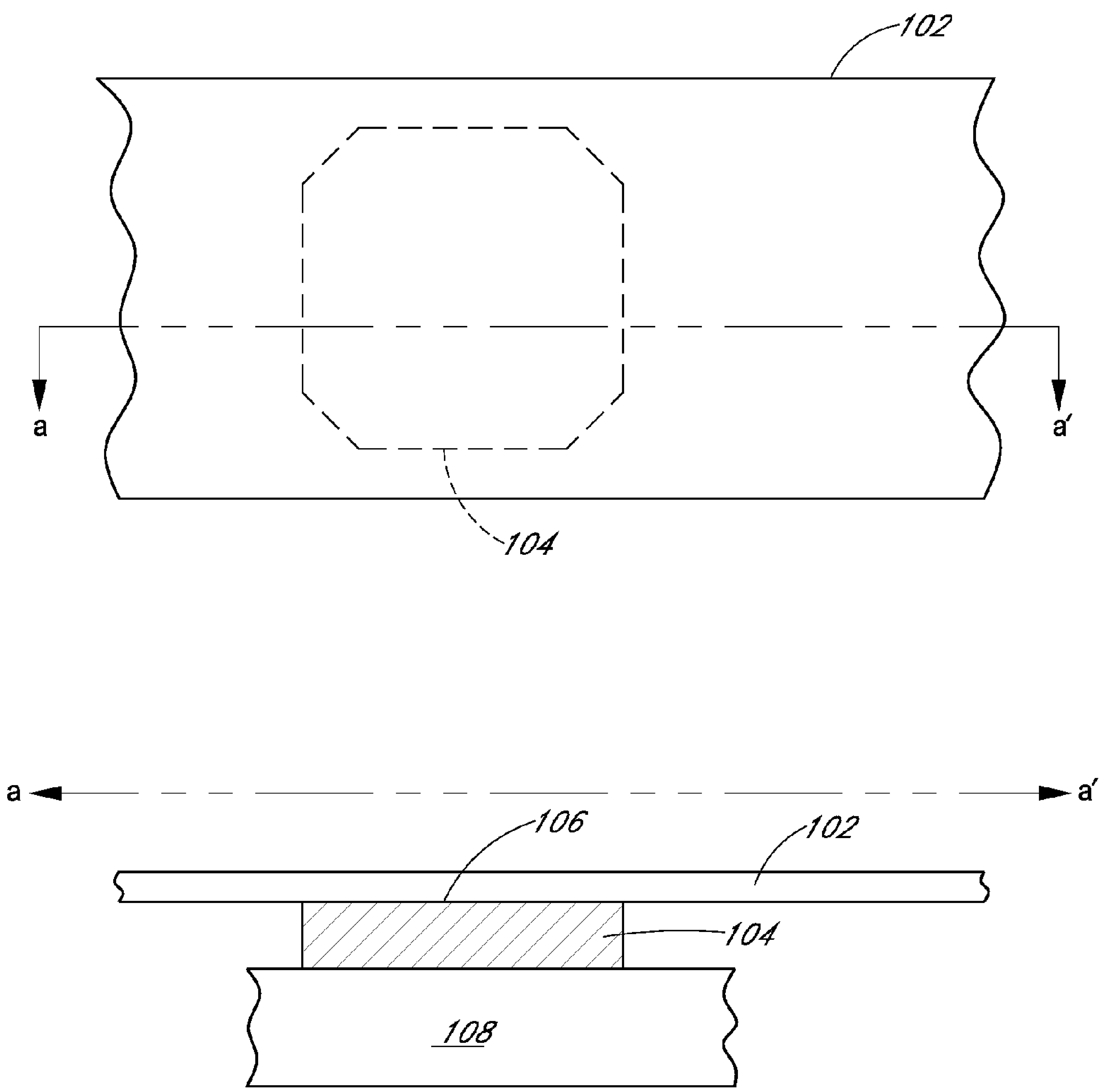


FIG. 1

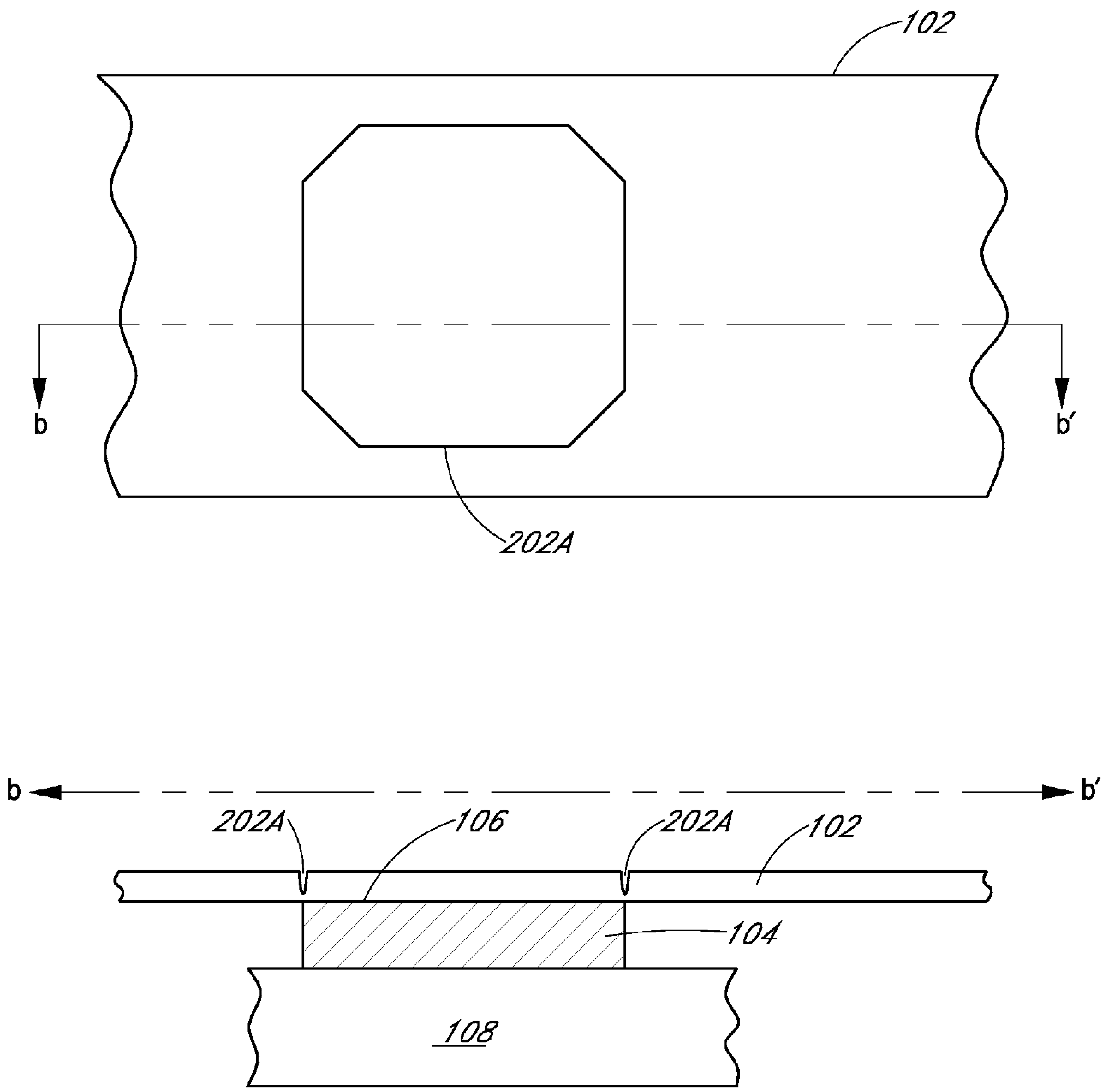


FIG. 2A

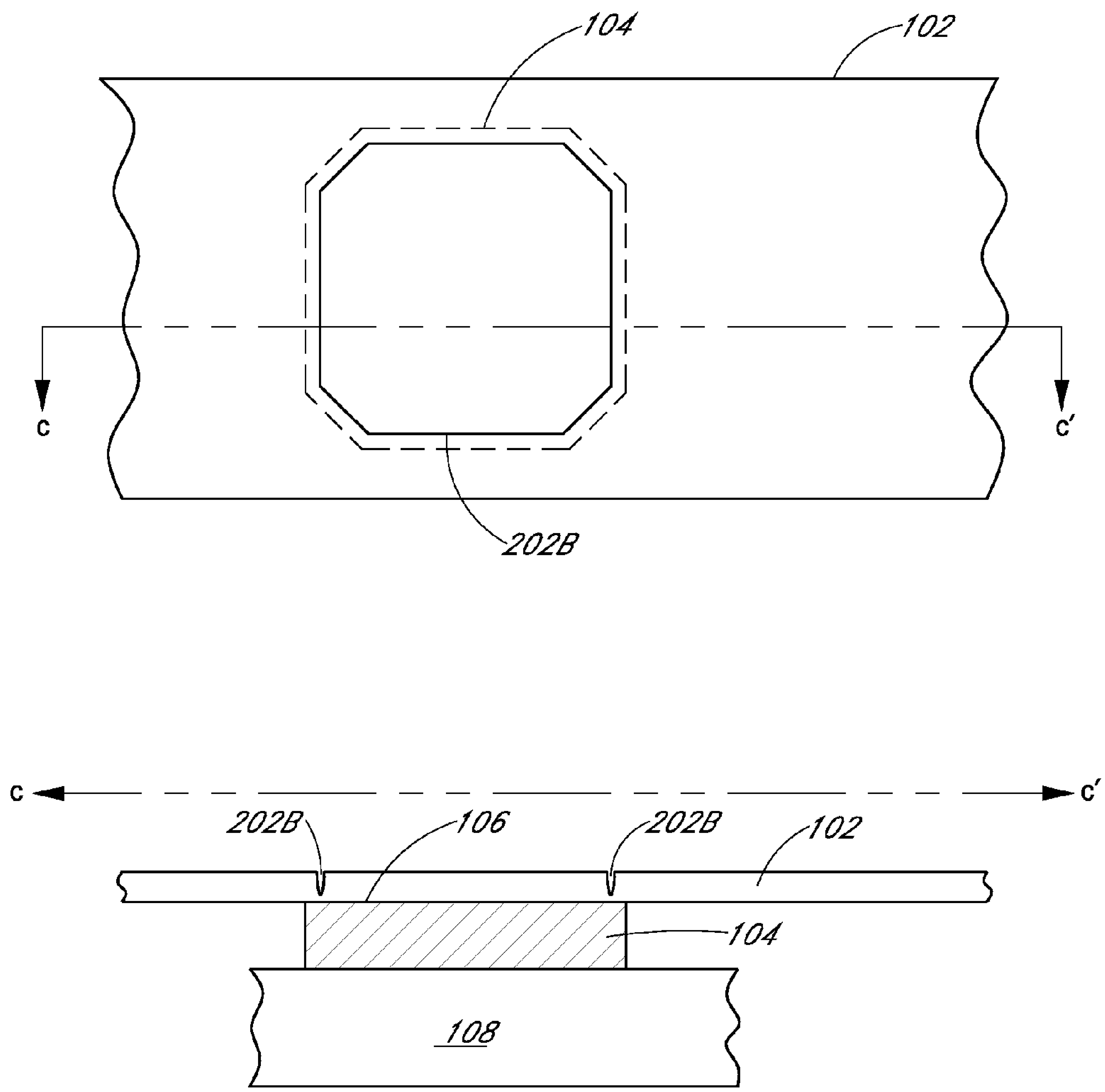


FIG. 2B

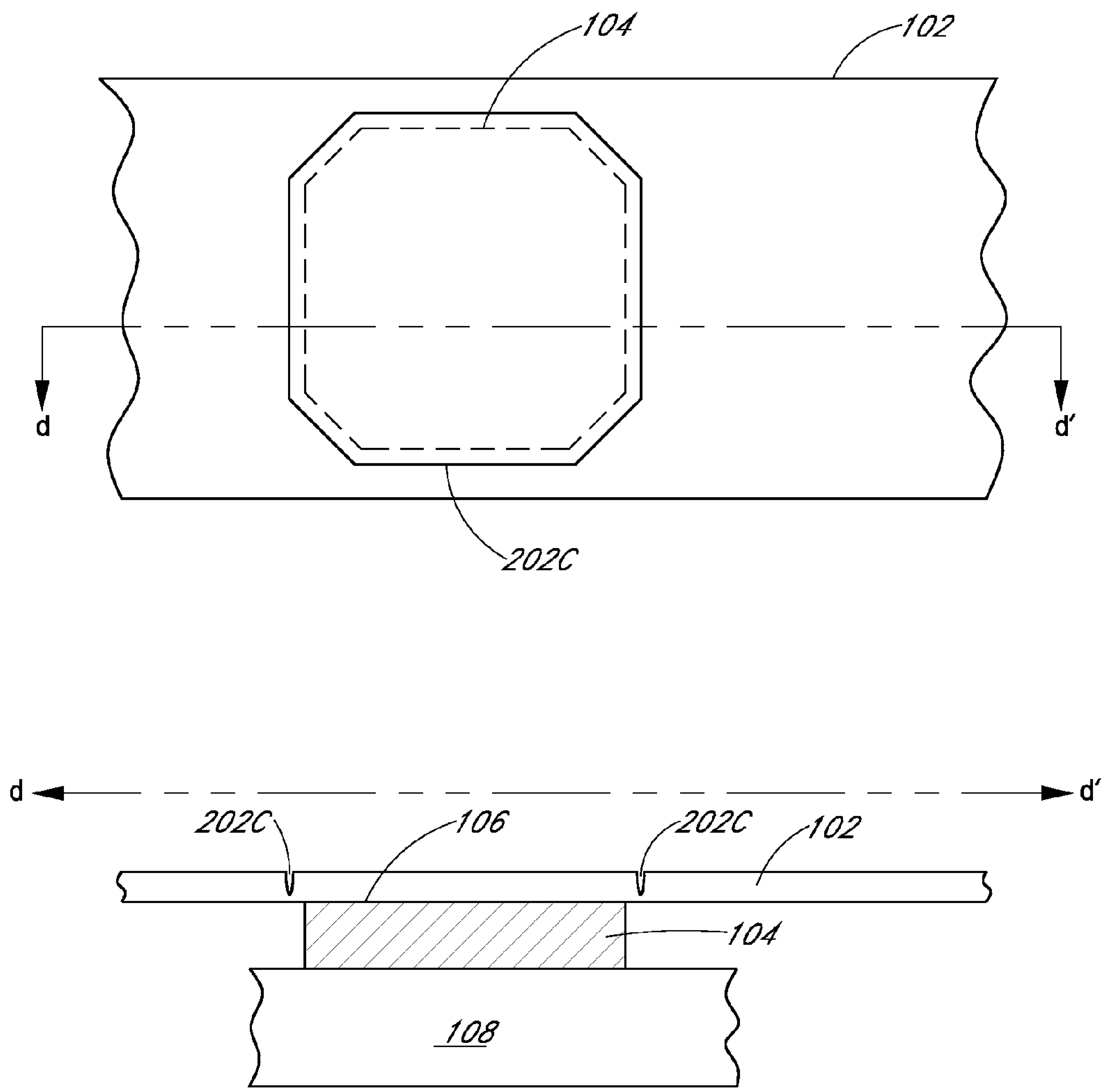


FIG. 2C

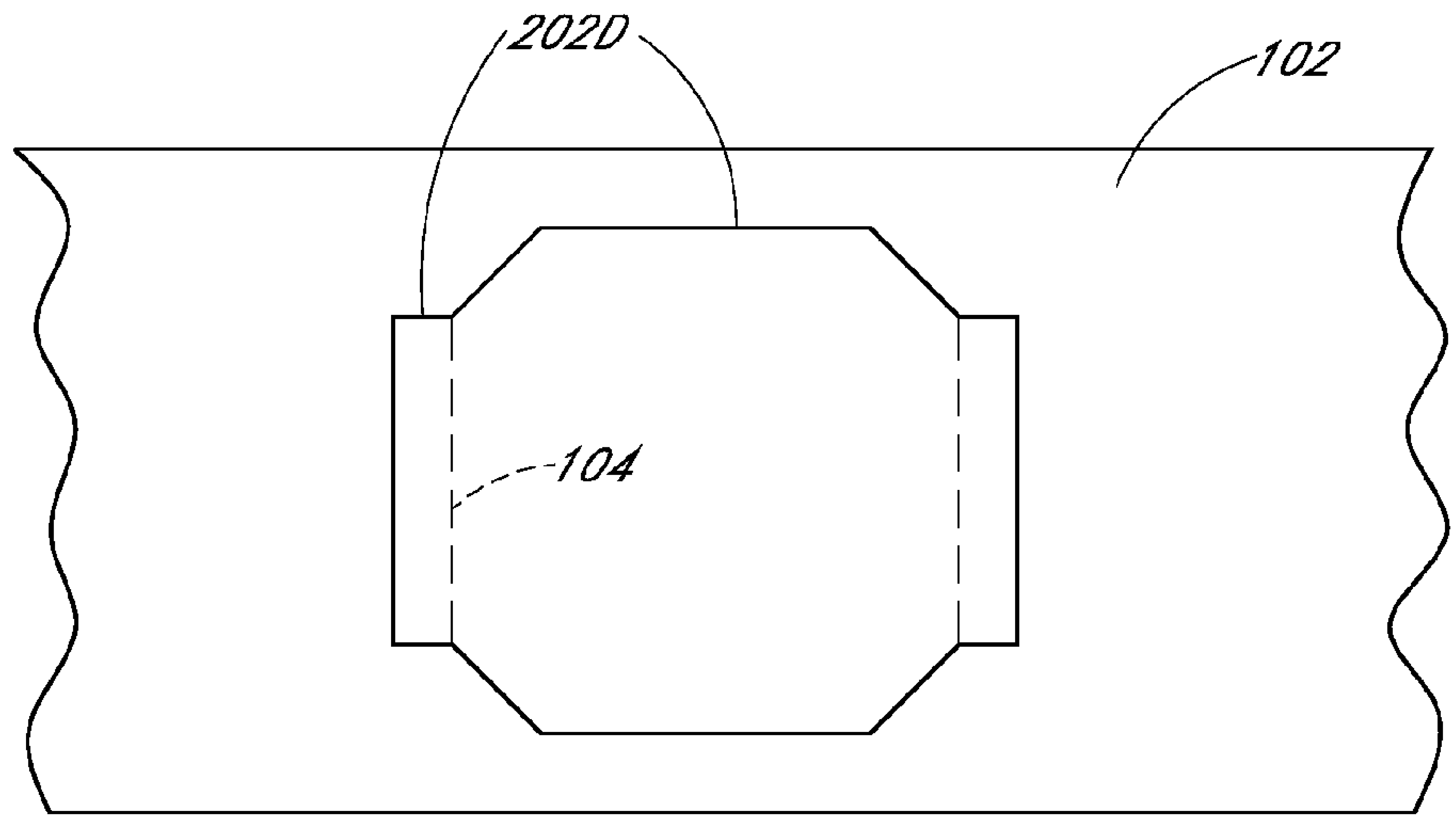


FIG. 2D

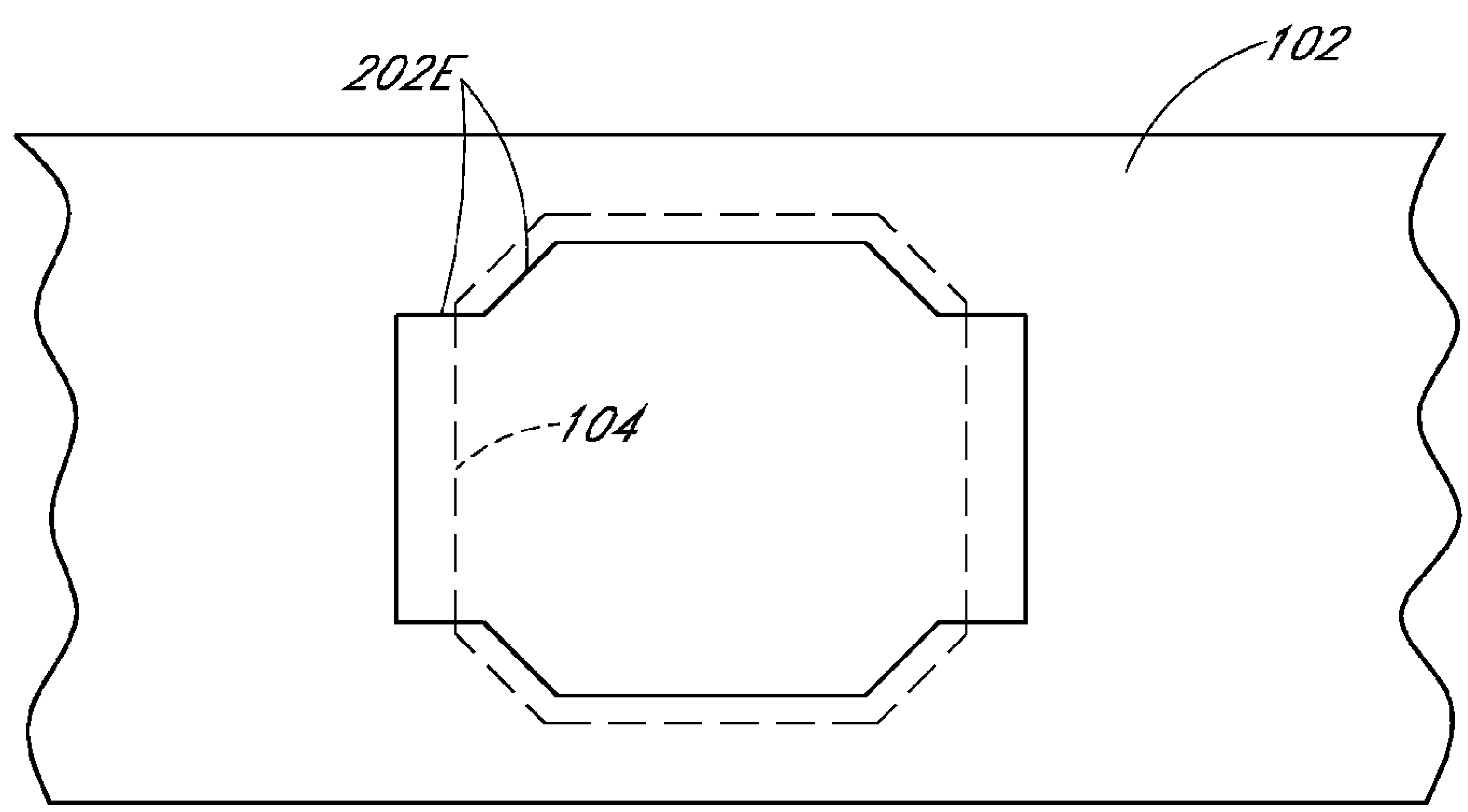


FIG. 2E

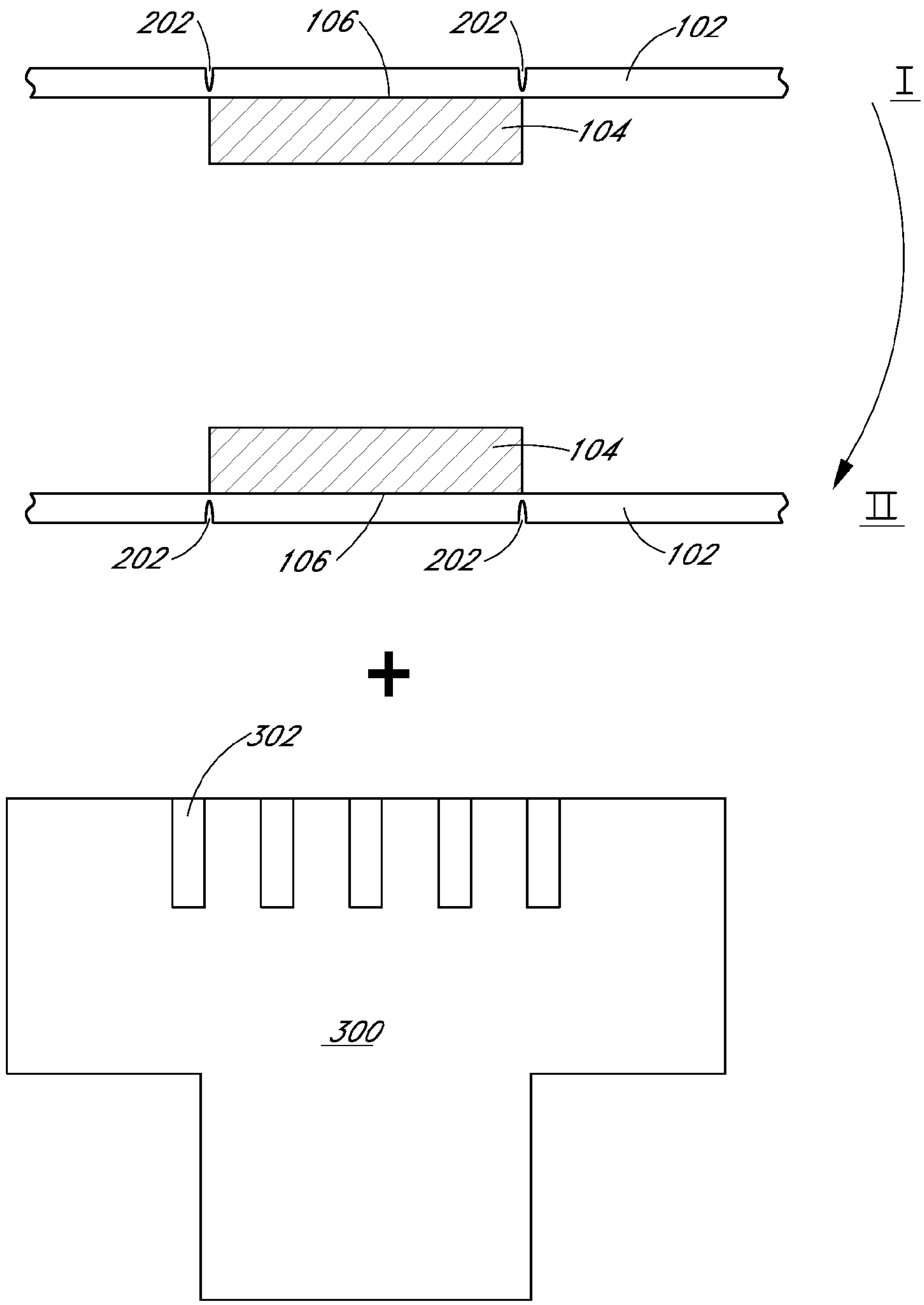


FIG. 3

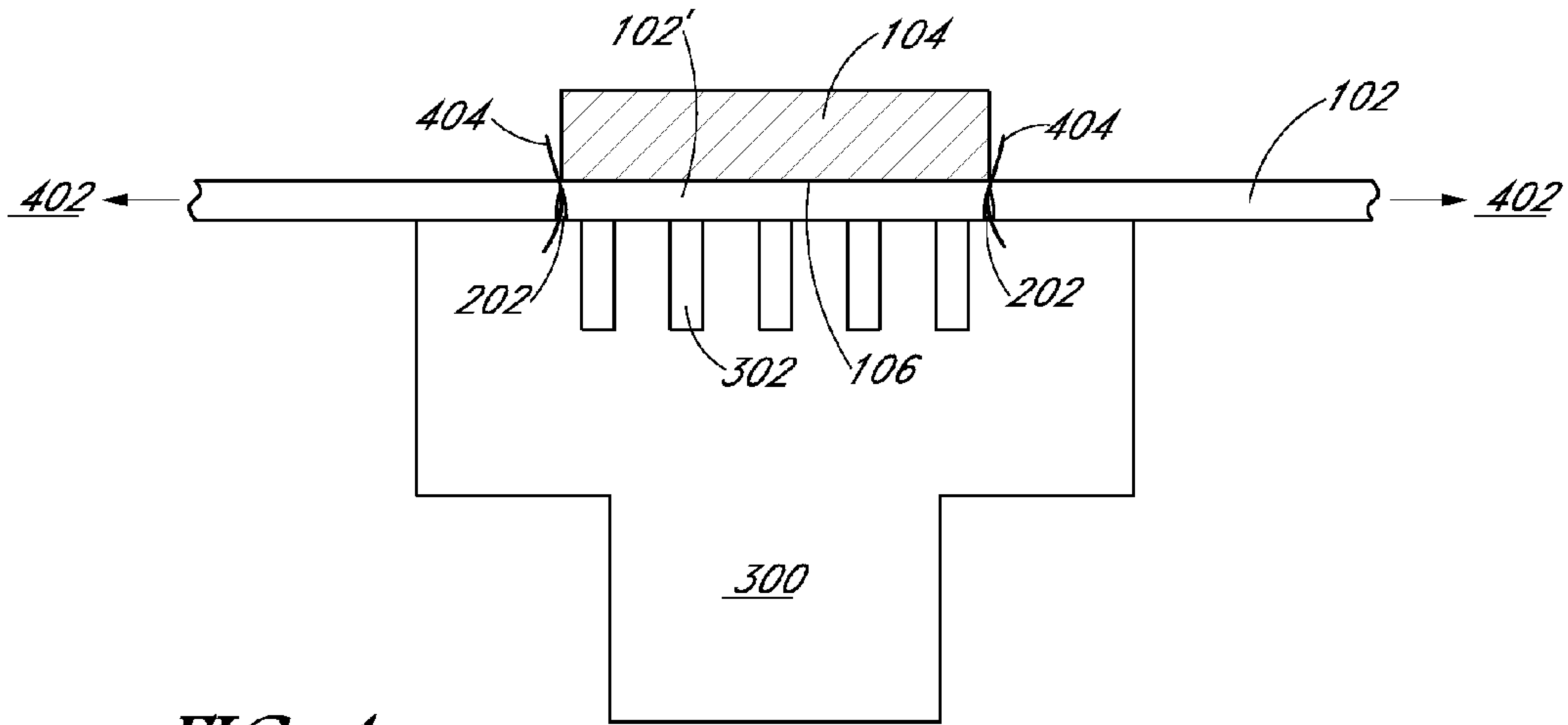


FIG. 4

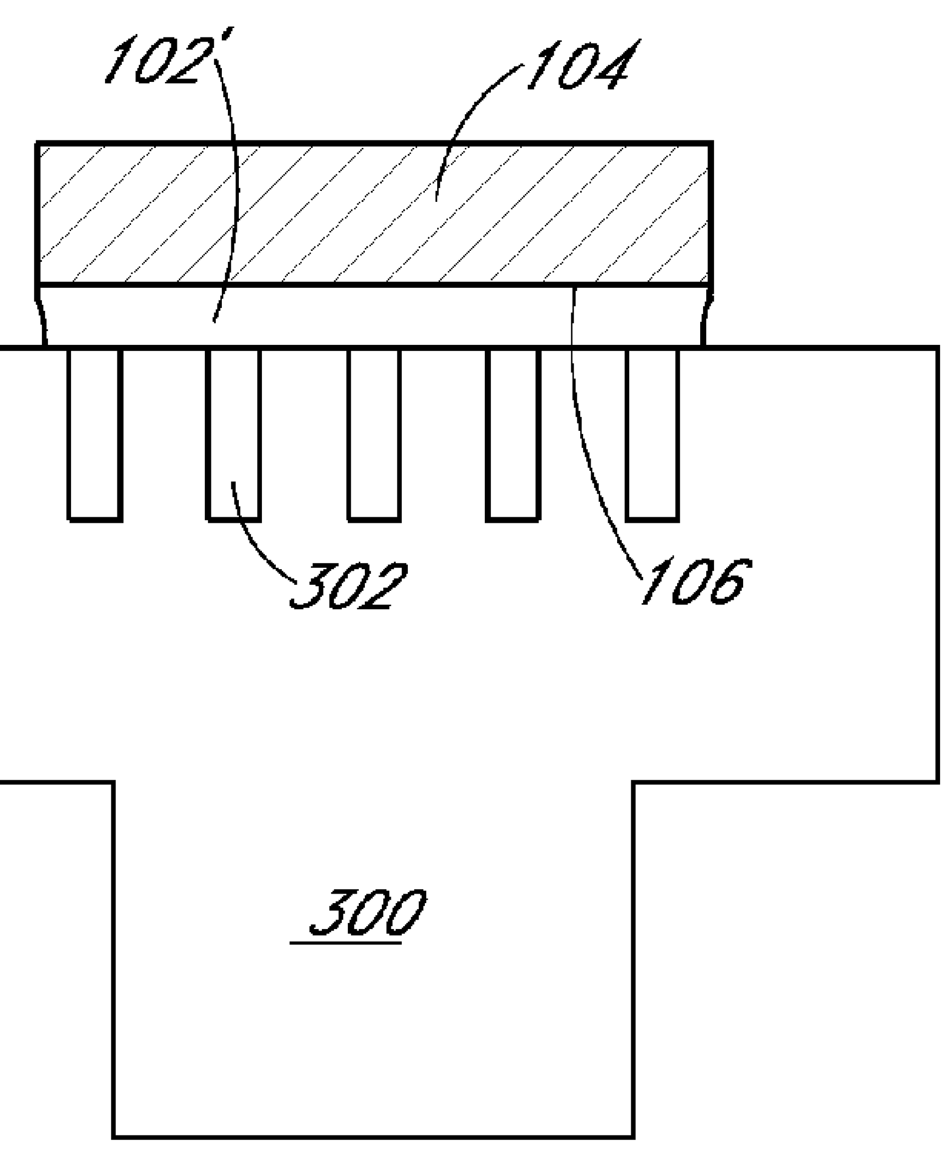


FIG. 5

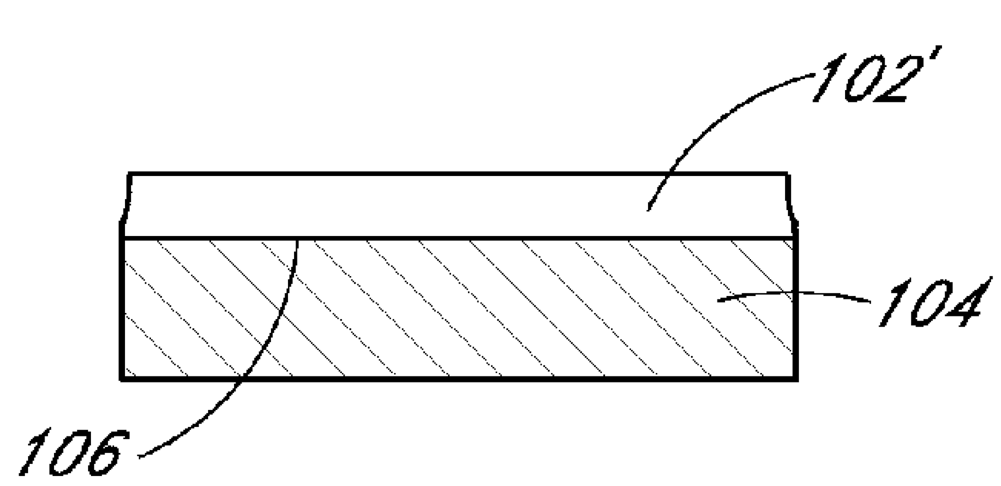


FIG. 6

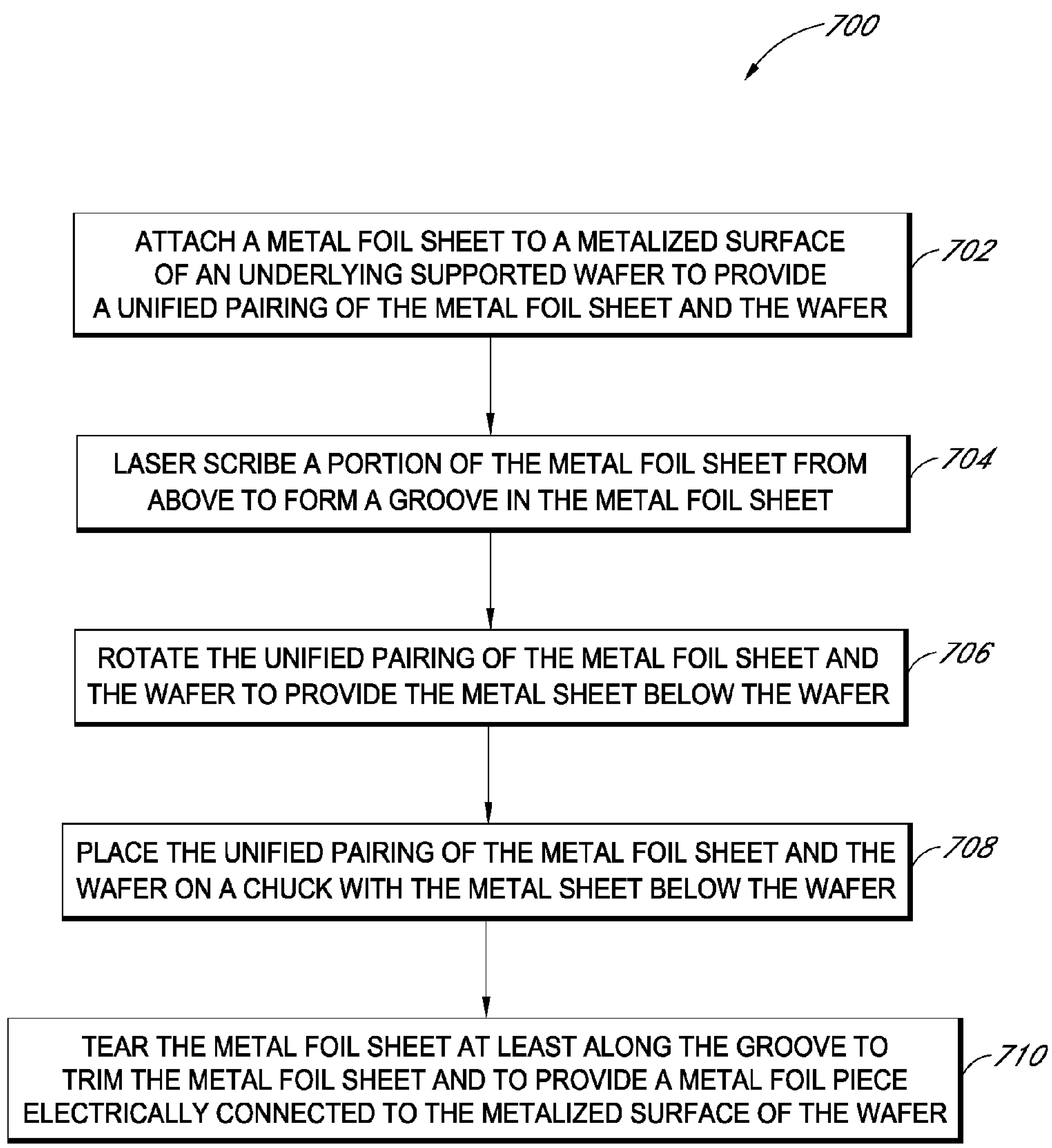

700
ATTACH A METAL FOIL SHEET TO A METALIZED SURFACE OF AN UNDERLYING SUPPORTED WAFER TO PROVIDE A UNIFIED PAIRING OF THE METAL FOIL SHEET AND THE WAFER
702
LASER SCRIBE A PORTION OF THE METAL FOIL SHEET FROM ABOVE TO FORM A GROOVE IN THE METAL FOIL SHEET
704
ROTATE THE UNIFIED PAIRING OF THE METAL FOIL SHEET AND THE WAFER TO PROVIDE THE METAL SHEET BELOW THE WAFER
706
PLACE THE UNIFIED PAIRING OF THE METAL FOIL SHEET AND THE WAFER ON A CHUCK WITH THE METAL SHEET BELOW THE WAFER
708
TEAR THE METAL FOIL SHEET AT LEAST ALONG THE GROOVE TO TRIM THE METAL FOIL SHEET AND TO PROVIDE A METAL FOIL PIECE ELECTRICALLY CONNECTED TO THE METALIZED SURFACE OF THE WAFER
710

FIG. 7

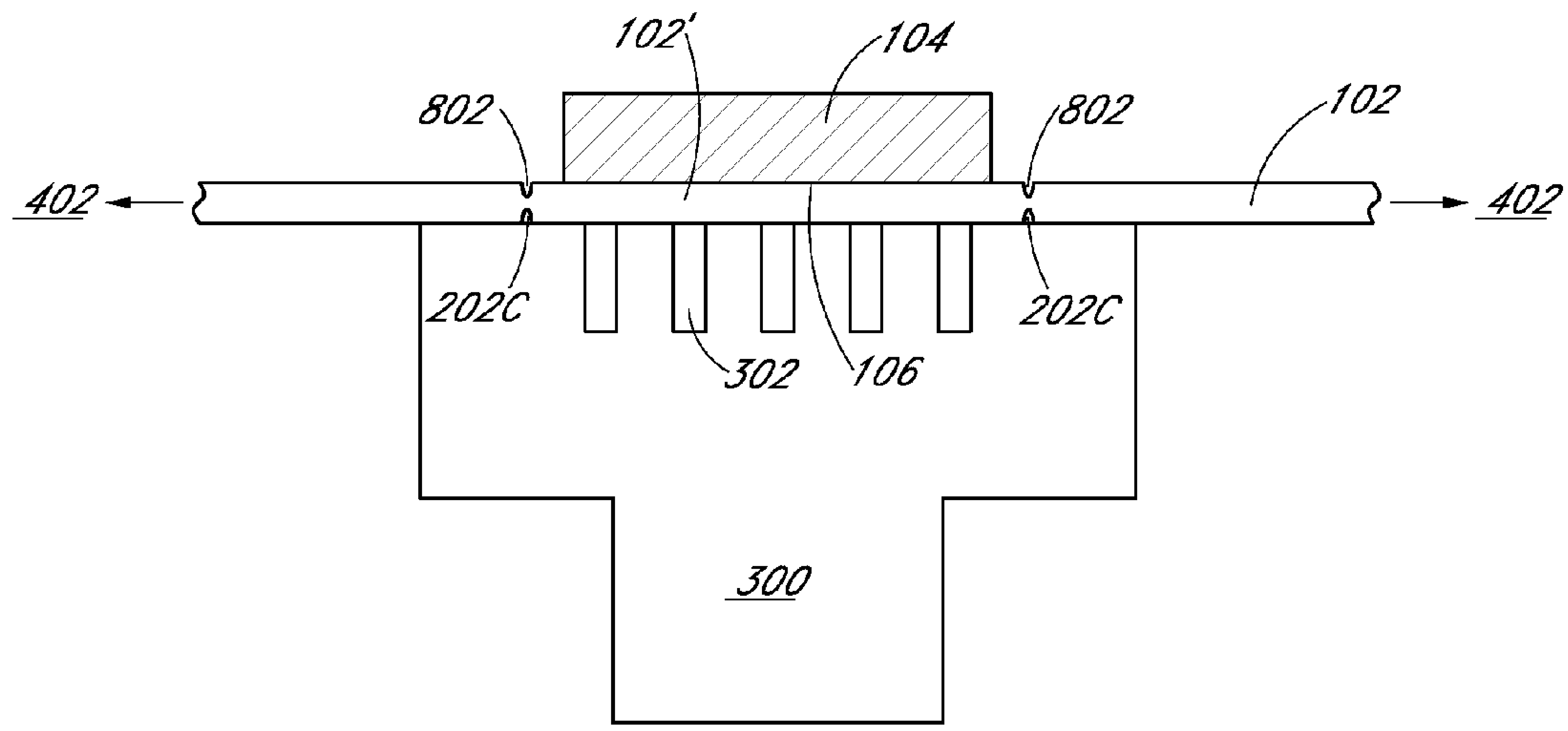


FIG. 8A

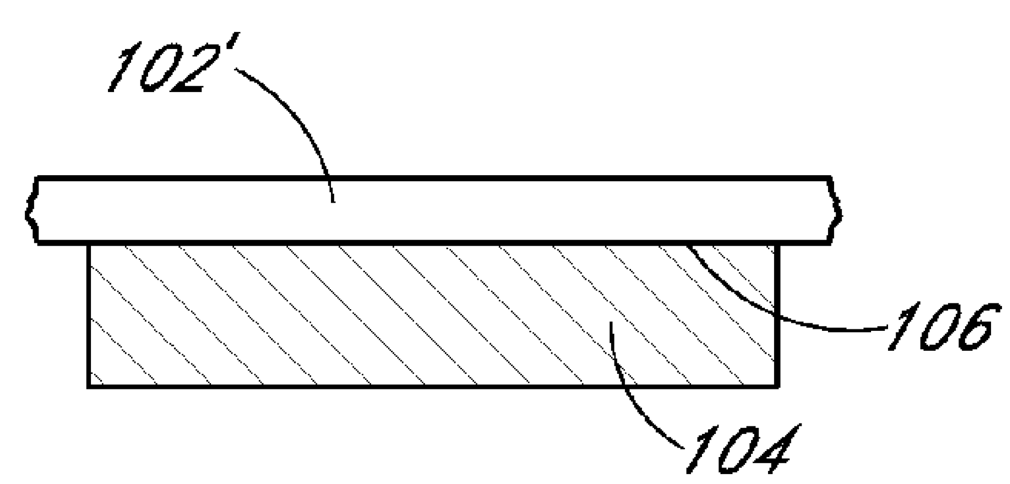


FIG. 8B

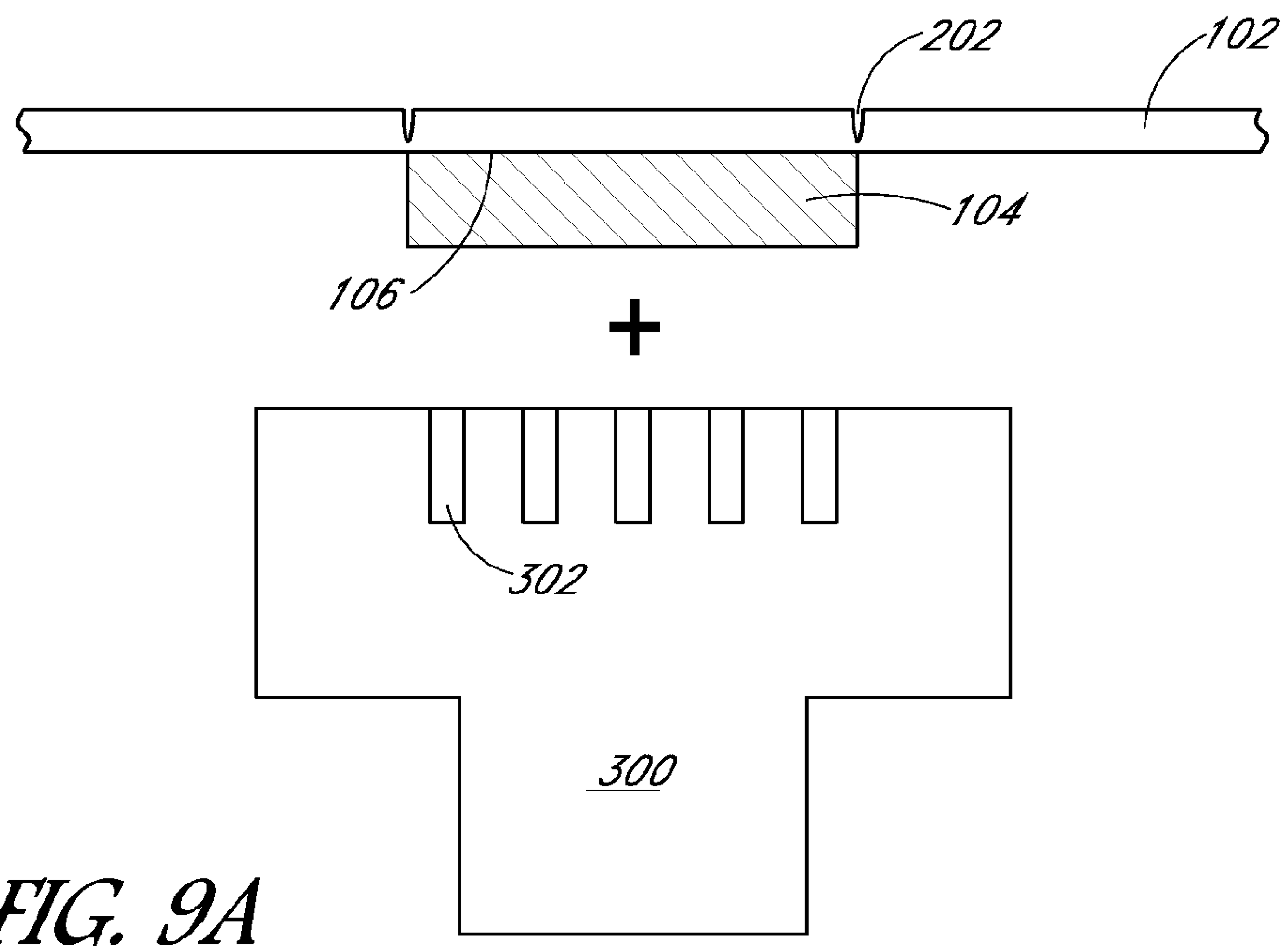


FIG. 9A

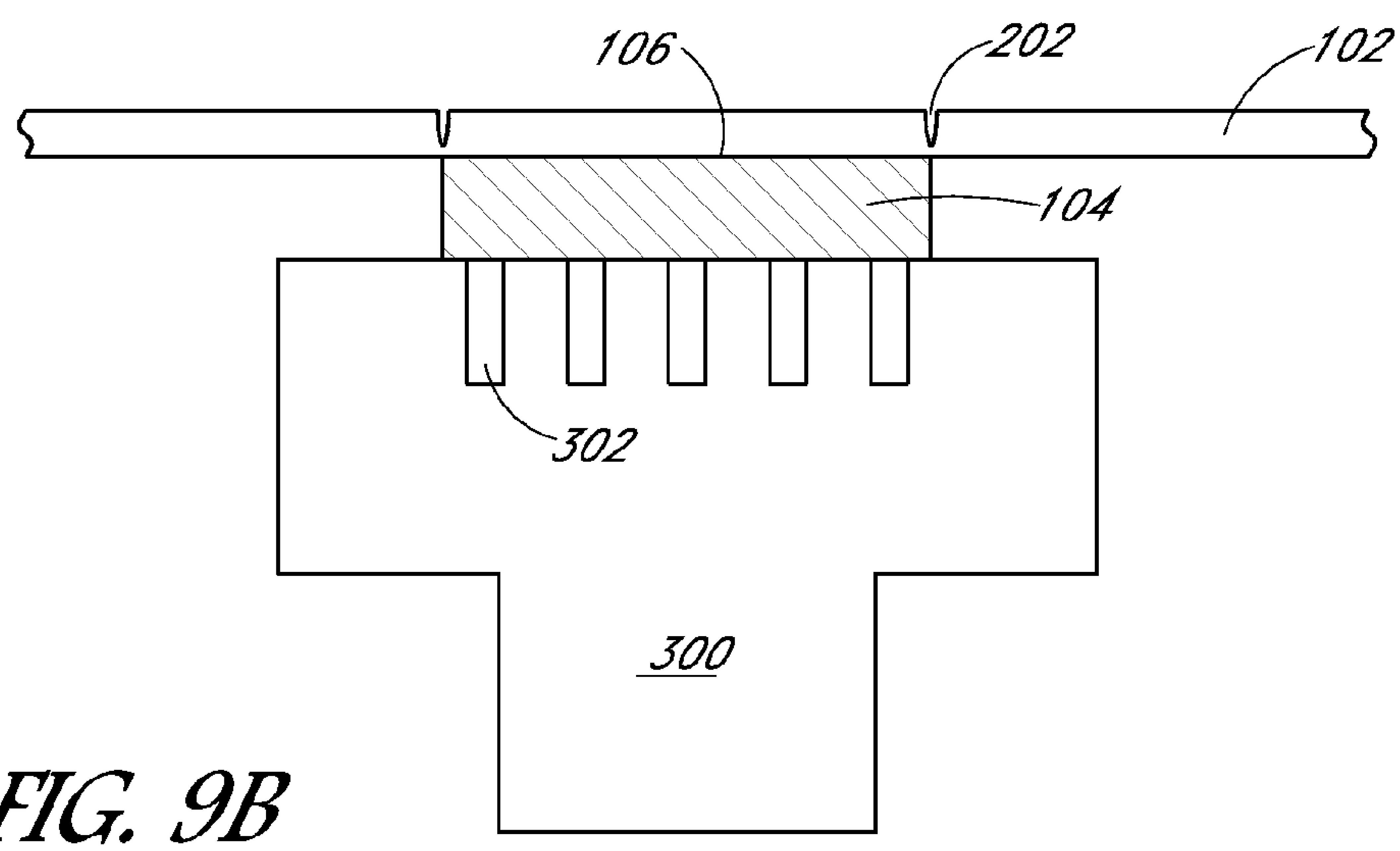


FIG. 9B

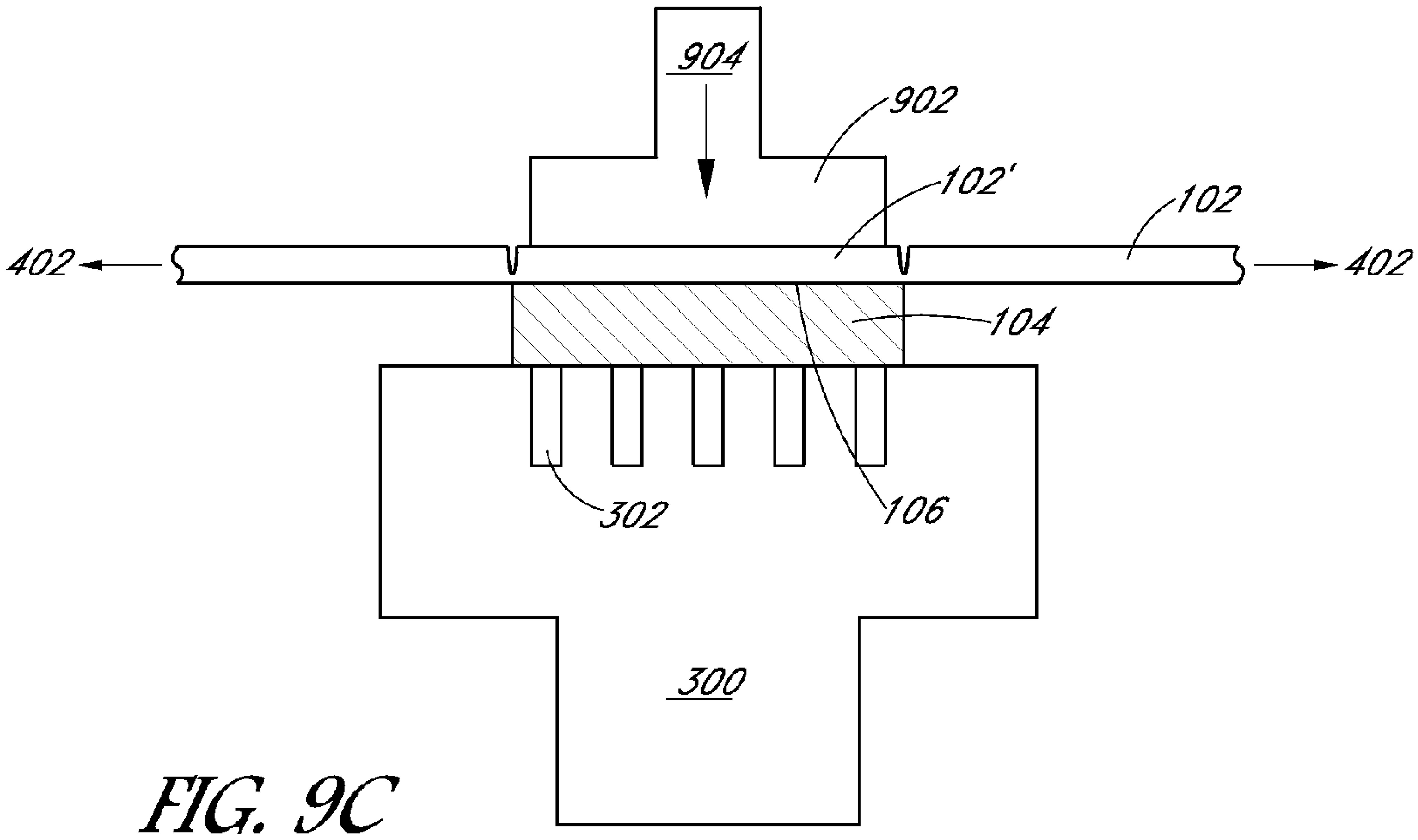


FIG. 9C

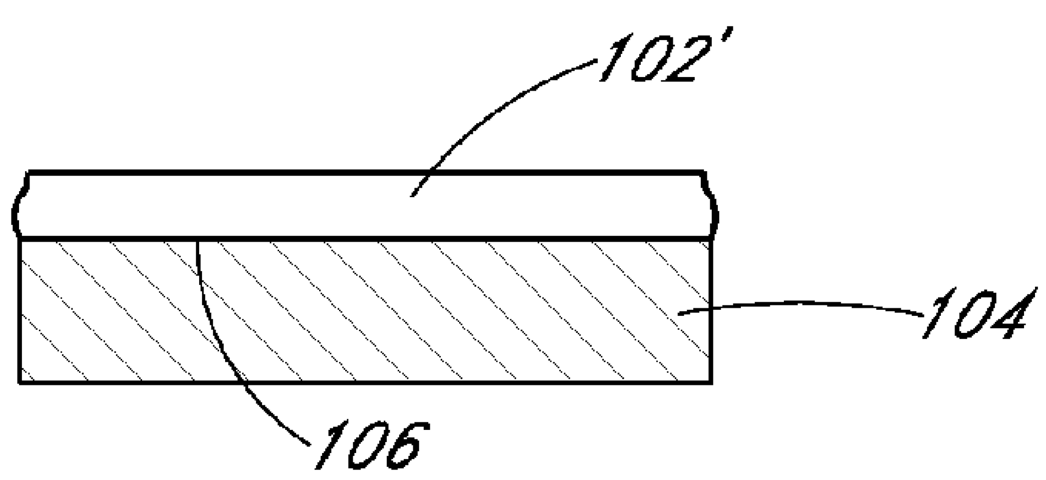


FIG. 9D

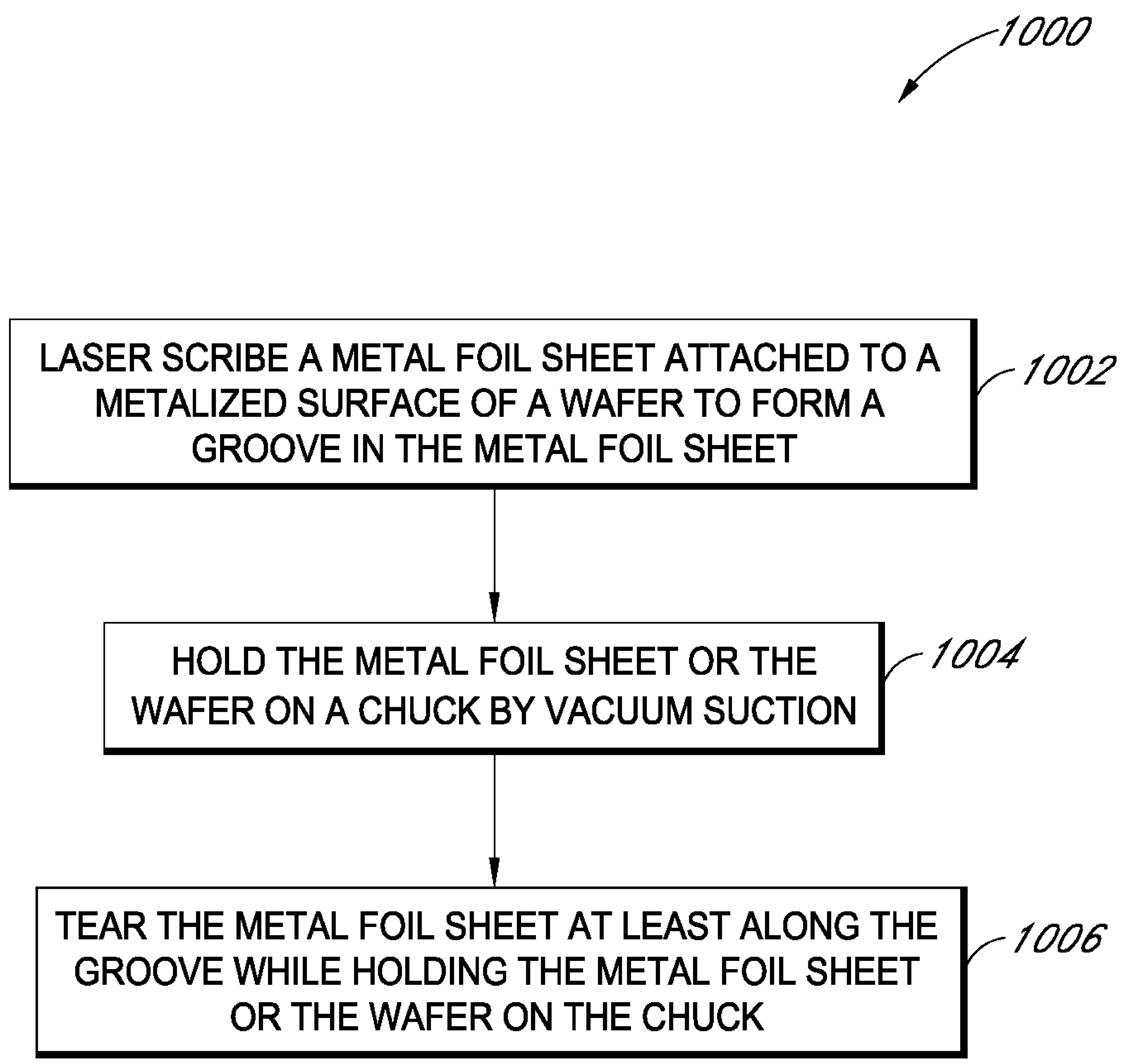

1000
LASER SCRIBE A METAL FOIL SHEET ATTACHED TO A METALIZED SURFACE OF A WAFER TO FORM A GROOVE IN THE METAL FOIL SHEET
1002
HOLD THE METAL FOIL SHEET OR THE WAFER ON A CHUCK BY VACUUM SUCTION
1004
TEAR THE METAL FOIL SHEET AT LEAST ALONG THE GROOVE WHILE HOLDING THE METAL FOIL SHEET OR THE WAFER ON THE CHUCK
1006

FIG. 10

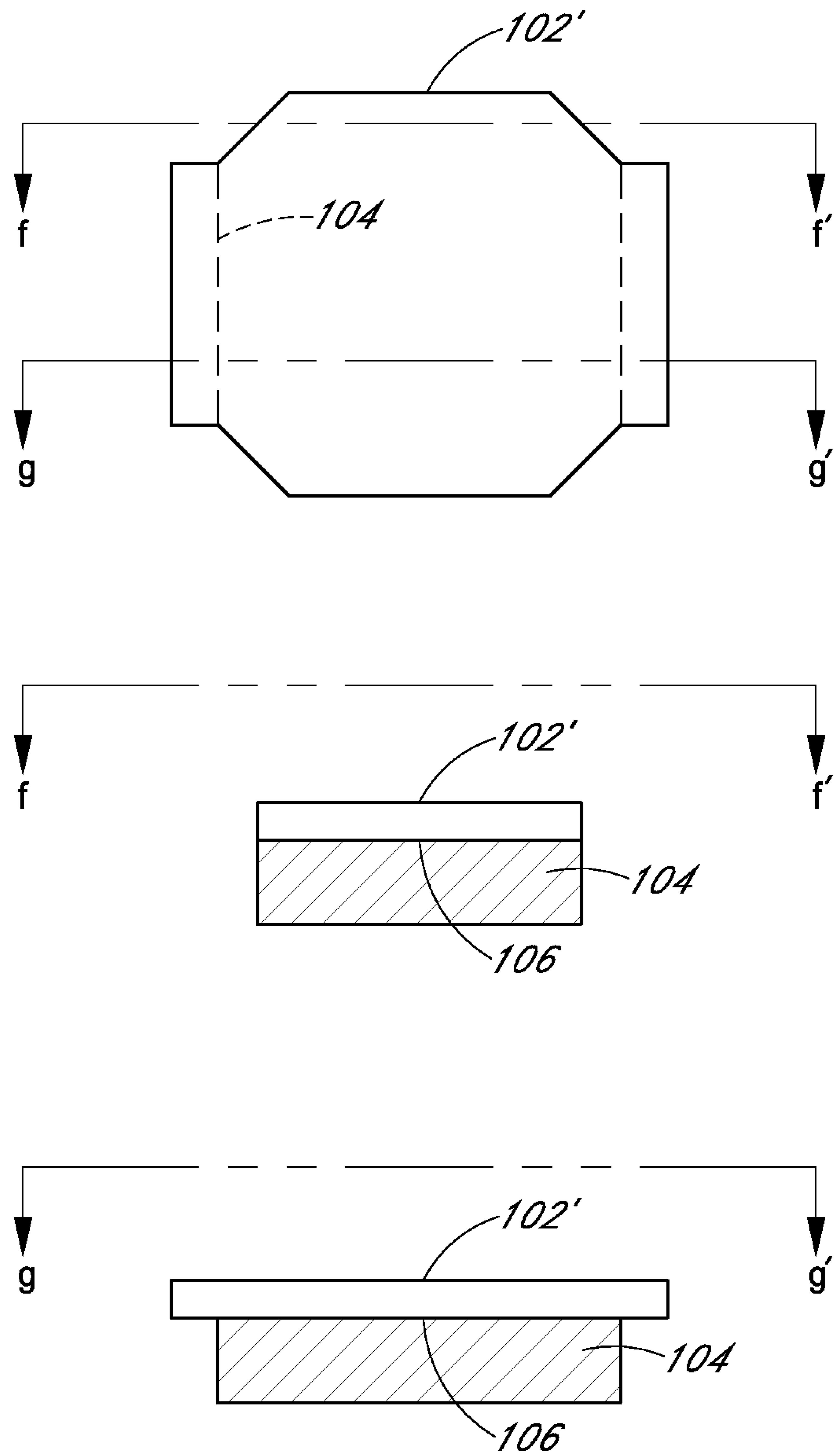


FIG. 11

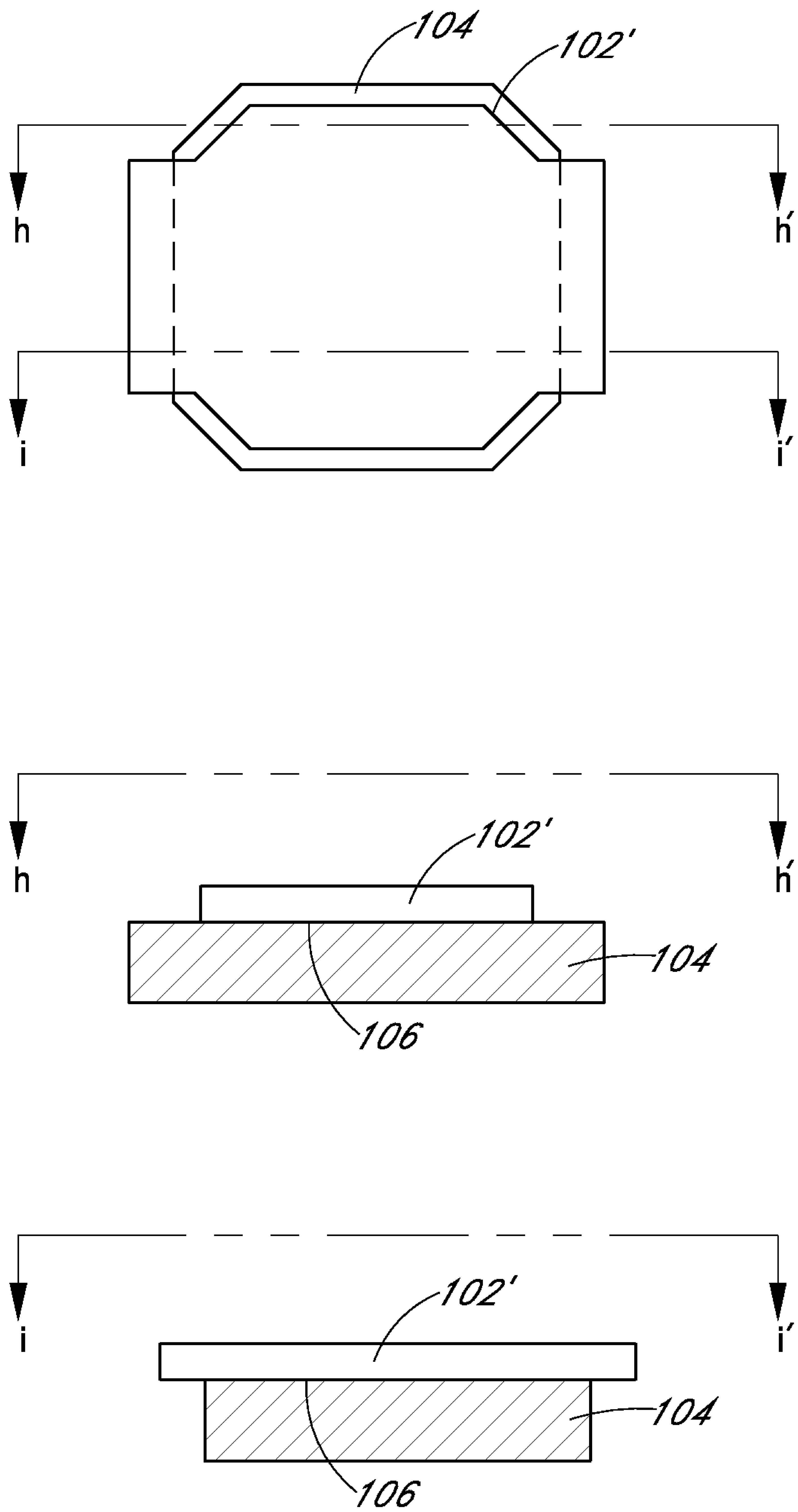


FIG. 12

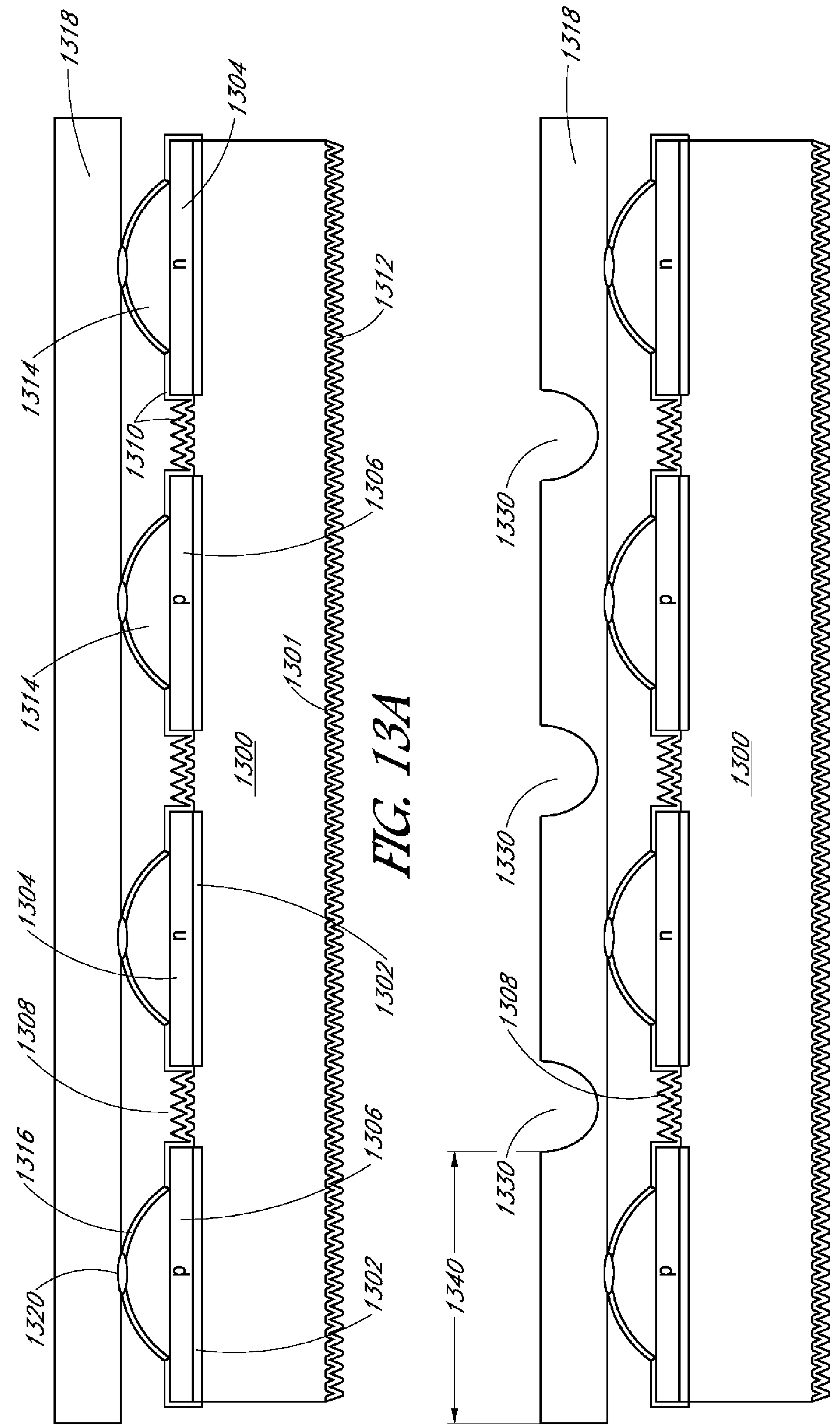


FIG. 13A

FIG. 13B

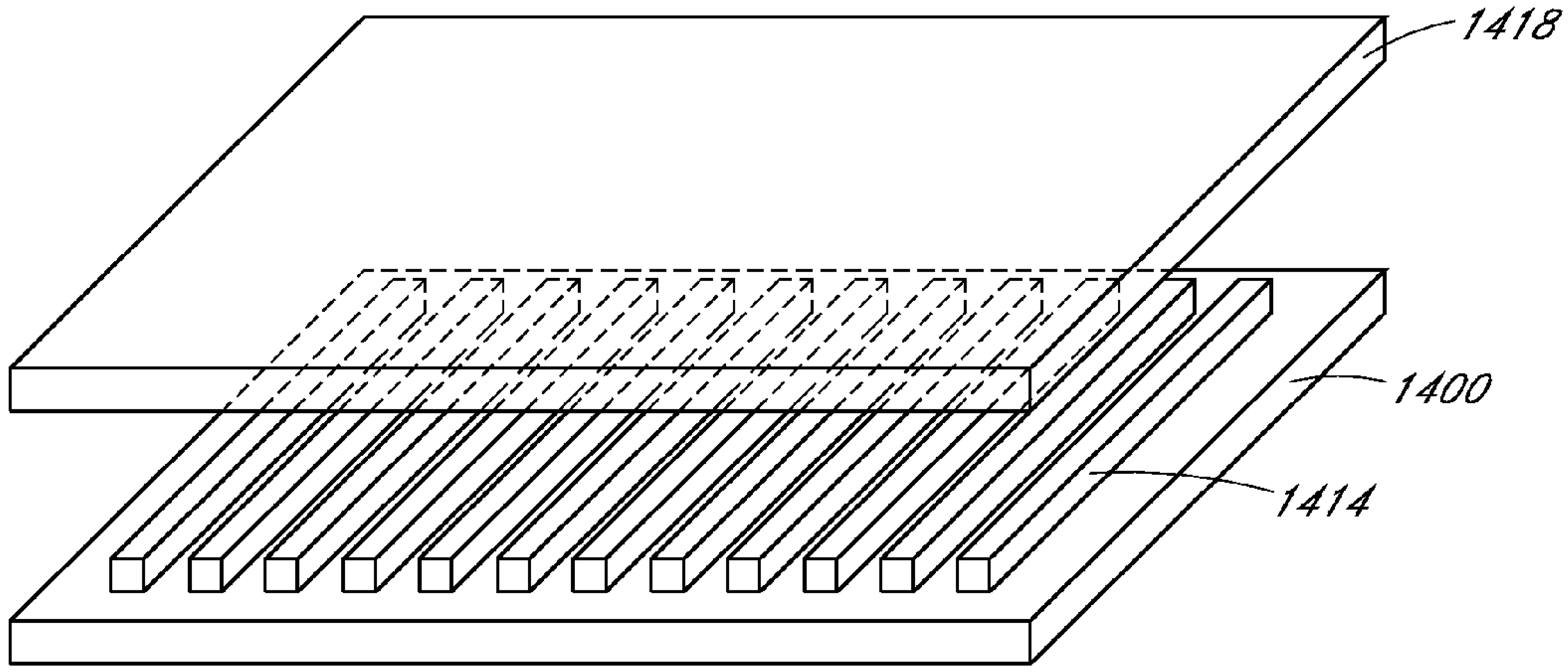


FIG. 14A

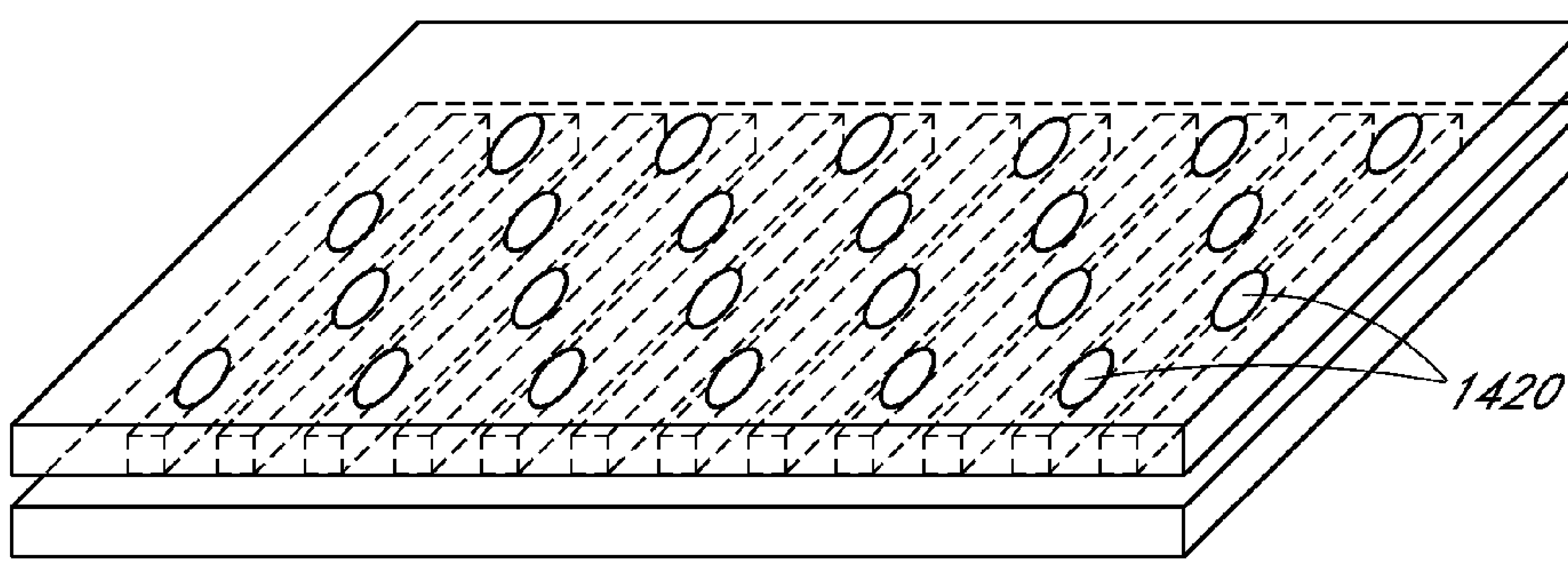


FIG. 14B

FOIL TRIM APPROACHES FOR FOIL-BASED METALLIZATION OF SOLAR CELLS

TECHNICAL FIELD

Embodiments of the present disclosure are in the field of renewable energy and, in particular, include foil trim approaches for foil-based metallization of solar cells and the resulting solar cells.

BACKGROUND

Photovoltaic cells, commonly known as solar cells, are well known devices for direct conversion of solar radiation into electrical energy. Generally, solar cells are fabricated on a semiconductor wafer or substrate using semiconductor processing techniques to form a p-n junction near a surface of the substrate. Solar radiation impinging on the surface of, and entering into, the substrate creates electron and hole pairs in the bulk of the substrate. The electron and hole pairs migrate to p-doped and n-doped regions in the substrate, thereby generating a voltage differential between the doped regions. The doped regions are connected to conductive regions on the solar cell to direct an electrical current from the cell to an external circuit coupled thereto.

Efficiency is an important characteristic of a solar cell as it is directly related to the capability of the solar cell to generate power. Likewise, efficiency in producing solar cells is directly related to the cost effectiveness of such solar cells. Accordingly, techniques for increasing the efficiency of solar cells, or techniques for increasing the efficiency in the manufacture of solar cells, are generally desirable. Some embodiments of the present disclosure allow for increased solar cell manufacture efficiency by providing novel processes for fabricating solar cell structures. Some embodiments of the present disclosure allow for increased solar cell efficiency by providing novel solar cell structures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**, **2**A-**2**E and **3**-**6** illustrate plan and cross-sectional views of various stages in the fabrication of a solar cell using foil-based metallization, in accordance with an embodiment of the present disclosure, wherein:

FIG. **1** illustrates a stage in solar cell fabrication involving attaching a metal foil sheet to a metallized surface of an underlying supported wafer to provide a unified pairing of the metal foil sheet and the wafer;

FIGS. **2**A-**2**E illustrate the pairing of FIG. **1** following laser scribing of a portion of the metal foil sheet from above to form a groove in the metal foil sheet, with various possibilities shown in FIGS. **2**A-**2**E;

FIG. **3** illustrates the pairing of FIGS. **2**A-**2**E following rotating the unified pairing of the metal foil sheet and the wafer to provide the metal sheet below the wafer;

FIG. **4** illustrates the pairing of FIG. **3** following placing of the unified pairing of the metal foil sheet and the wafer on a chuck with the metal sheet below the wafer;

FIG. **5** illustrates the pairing of FIG. **4** following tearing of the metal foil sheet at least along the groove to trim the metal foil sheet and to leave remaining a metal foil piece electrically connected to the metallized surface of the wafer; and

FIG. **6** illustrates the pairing of FIG. **5** as removed from the chuck.

FIG. **7** is a flowchart listing operations in a method of fabricating a solar cell as corresponding to FIGS. **1**, **2**A-**2**E and **3**-**6**, in accordance with an embodiment of the present disclosure.

FIGS. **8**A and **8**B illustrate cross-sectional views of various stages in the fabrication of a solar cell using foil-based metallization, in accordance with another embodiment of the present disclosure.

FIGS. **9**A-**9**D illustrate cross-sectional views of various stages in the fabrication of a solar cell using foil-based metallization, in accordance with another embodiment of the present disclosure.

FIG. **10** is a flowchart listing operations in a general method of fabricating a solar cell, in accordance with an embodiment of the present disclosure.

FIG. **11** illustrates plan and cross-sectional views of a solar cell having foil-based metallization, in accordance with an embodiment of the present disclosure.

FIG. **12** illustrates plan and cross-sectional views of another solar cell having foil-based metallization, in accordance with another embodiment of the present disclosure.

FIGS. **13**A and **13**B illustrate cross-sectional views of various stages in the fabrication of a solar cell using foil-based metallization, in accordance with another embodiment of the present disclosure.

FIGS. **14**A and **14**B illustrate angled views of various stages in the fabrication of a solar cell using foil-based metallization, in accordance with another embodiment of the present disclosure.

DETAILED DESCRIPTION

The following detailed description is merely illustrative in nature and is not intended to limit the embodiments of the subject matter or the application and uses of such embodiments. As used herein, the word "exemplary" means "serving as an example, instance, or illustration." Any implementation described herein as exemplary is not necessarily to be construed as preferred or advantageous over other implementations. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description.

This specification includes references to "one embodiment" or "an embodiment." The appearances of the phrases "in one embodiment" or "in an embodiment" do not necessarily refer to the same embodiment. Particular features, structures, or characteristics may be combined in any suitable manner consistent with this disclosure.

Terminology. The following paragraphs provide definitions and/or context for terms found in this disclosure (including the appended claims):

"Comprising." This term is open-ended. As used in the appended claims, this term does not foreclose additional structure or steps.

"Configured To." Various units or components may be described or claimed as "configured to" perform a task or tasks. In such contexts, "configured to" is used to connote structure by indicating that the units/components include structure that performs those task or tasks during operation. As such, the unit/component can be said to be configured to perform the task even when the specified unit/component is not currently operational (e.g., is not on/active). Reciting that a unit/circuit/component is "configured to" perform one or more tasks is expressly intended not to invoke 35 U.S.C. §112, sixth paragraph, for that unit/component.

"First," "Second," etc. As used herein, these terms are used as labels for nouns that they precede, and do not imply any type of ordering (e.g., spatial, temporal, logical, etc.). For example, reference to a "first" solar cell does not necessarily imply that this solar cell is the first solar cell in a sequence;

instead the term "first" is used to differentiate this solar cell from another solar cell (e.g., a "second" solar cell).

"Coupled"—The following description refers to elements or nodes or features being "coupled" together. As used herein, unless expressly stated otherwise, "coupled" means that one element/node/feature is directly or indirectly joined to (or directly or indirectly communicates with) another element/node/feature, and not necessarily mechanically.

In addition, certain terminology may also be used in the following description for the purpose of reference only, and thus are not intended to be limiting. For example, terms such as "upper", "lower", "above", and "below" refer to directions in the drawings to which reference is made. Terms such as "front", "back", "rear", "side", "outboard", and "inboard" describe the orientation and/or location of portions of the component within a consistent but arbitrary frame of reference which is made clear by reference to the text and the associated drawings describing the component under discussion. Such terminology may include the words specifically mentioned above, derivatives thereof, and words of similar import.

"Inhibit"—As used herein, inhibit is used to describe a reducing or minimizing effect. When a component or feature is described as inhibiting an action, motion, or condition it may completely prevent the result or outcome or future state completely. Additionally, "inhibit" can also refer to a reduction or lessening of the outcome, performance, and/or effect which might otherwise occur. Accordingly, when a component, element, or feature is referred to as inhibiting a result or state, it need not completely prevent or eliminate the result or state.

Foil trim approaches for foil-based metallization of solar cells and the resulting solar cells are described herein. In the following description, numerous specific details are set forth, such as specific process flow operations, in order to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to one skilled in the art that embodiments of the present disclosure may be practiced without these specific details. In other instances, well-known fabrication techniques, such as lithography and patterning techniques, are not described in detail in order to not unnecessarily obscure embodiments of the present disclosure. Furthermore, it is to be understood that the various embodiments shown in the figures are illustrative representations and are not necessarily drawn to scale.

Disclosed herein are methods of fabricating solar cells. In one embodiment, a method of fabricating a solar cell involves attaching a metal foil sheet to a metallized surface of an underlying supported wafer to provide a unified pairing of the metal foil sheet and the wafer. The method also involves, subsequent to attaching the metal foil sheet, laser scribing a portion of the metal foil sheet from above to form a groove in the metal foil sheet. The method also involves, subsequent to laser scribing the metal foil sheet, rotating the unified pairing of the metal foil sheet and the wafer to provide the metal sheet below the wafer. The method also involves, subsequent to the rotating, placing the unified pairing of the metal foil sheet and the wafer on a chuck with the metal sheet below the wafer. The method also involves tearing the metal foil sheet at least along the groove to trim the metal foil sheet.

In another embodiment, a method of fabricating a solar cell involves laser scribing a metal foil sheet attached to a metallized surface of a wafer to form a groove in the metal foil sheet. The method also involves, subsequent to the laser scribing, holding the metal foil sheet or the wafer on a chuck by vacuum suction. The method also involves, while holding the metal foil sheet or the wafer on the chuck, tearing the metal foil sheet at least along the groove to trim the metal foil sheet and to leave remaining a metal foil piece electrically connected to the metallized surface of the wafer.

Also disclosed herein are solar cells. In one embodiment, a solar cell includes a wafer having a metallized surface and having a perimeter. The solar cell also includes a metal foil piece electrically connected to the metallized surface of the wafer. The metal foil piece has a perimeter including a first portion in alignment with or within a first portion of the perimeter of the wafer, and including a second portion overhanging a second portion of the perimeter of the wafer.

One or more embodiments described herein may involve a foil trimming approach for solar cell device metallization fabrication. In an embodiment, to trim a foil attached to a cell (e.g., a foil welded to a solar cell by laser welding), the foil is grooved without fully cutting of the foil. The foil and cell assembly is then flipped or rotated and the foil is vacuum held in place on a chuck while a mechanical tearing of the foil is performed along the groove. In some embodiments, additional partial lasing may be performed subsequent to flipping or rotating to improve tearing of the foil.

To provide context, metal foils are typically purchased in sheet form for lowest cost. In a foil based solar cell metallization process, a wafer may be placed on a chuck, and a foil may then be placed over the wafer. The foil is then fit to the wafer with a mechanical action and welded to the cell. The contact fingers within the foil may then be patterned by cutting, either with a groove and etch approach or by fully lasing through the foil to the cell with a sacrificial layer under the laser cut area.

After the above operations, the excess foil must be trimmed off from the solar cell/foil pairing. In order to perform in a same operation as the above finger patterning process, either a groove and etch approach or sacrificial layer approach is needed to be compatible with the foil trim operation. However, in both cases, the foil is typically cut inside the perimeter of the cell along at least some edges. When trimming the foil inside the perimeter of the cell and cutting fully through the foil, the laser substantially heats the edge of the wafer where cracking is most likely to be induced. To reduce the impact of such heating on the cell, an underlying sacrificial layer can be used. However, such a layer must be very close to the wafer edge and the resulting manufacturing process generally involves an additional operation such as edge coating to create the sacrificial barrier. In accordance with one or more embodiments of the present disclosure, it is preferable to avoid an edge coating operation. In some embodiments, it is also preferable to avoid groove and etch processing for the foil trim in order to avoid laser damage issues and wet chemical processing of wafers with overhanging foils.

Addressing one or more of the above issues, in accordance with an embodiment of the present disclosure, a foil trim is performed along the wafer edge by first lasing a trench approximately between 80 and 95% of the way through the foil, but not completely through the foil. The foil and attached wafer are then released from the initial support (which may be a chuck), flipped or rotated, and vacuum attached with the foil side down to a new chuck. The excess foil is then mechanically torn from the wafer. The torn edge may be inside the wafer edges along some edges and overhanging along other edges, e.g., to provide an overhanging interconnect tab. In one embodiment, when the foil groove is not covered by the wafer, a second lasing process may be performed to aid with the separation of the excess foil. Furthermore, in some embodiments, approaches described herein can be implemented to reduce damage to the wafer after a foil attachment process. In one embodiment, a method to reduce damage to the wafer involves use of a "damage buffer" material deposited (e.g., via printing) near the edge of the wafer. A laser is then used to pattern down to the damage buffer in a continuous or non-continuous method, e.g., by ablating 50 to 99.9% of the total perimeter of the foil completely through (as in a perforation method). A tear method may then be applied to remove any residual metal, which may remain deliberately or as otherwise.

Other embodiments described below involve completely cutting through the foil for portions of foil outside the wafer edge perimeter, i.e., for overhanging regions of foil. Such an approach may minimize the sections that must be torn. Yet other embodiments described below involve leaving the wafer on its original chuck and tearing the foil, avoiding an additional handling operation. However, in this case the foil is not held by vacuum so the attachment to the cell may be exposed to additional mechanical stress. As such, in one embodiment, a top platen is pressed onto the assembly to aid in reducing mechanical stresses.

In a first aspect, a foil trim approach is applied with a solar cell and foil pairing oriented foil-side down on a chuck. Consistent with the first aspect, FIGS. **1**, **2**A-**2**E and **3**-**6** illustrate plan and cross-sectional views of various stages in the fabrication of a solar cell using foil-based metallization. FIG. **7** is a flowchart **700** listing operations in a method of fabricating a solar cell as corresponding to FIGS. **1**, **2**A-**2**E and **3**-**6**, in accordance with an embodiment of the present disclosure.

Referring to operation **702** of flowchart **700**, a method of fabricating a solar cell involves attaching a metal foil sheet to a metallized surface of an underlying supported wafer to provide a unified pairing of the metal foil sheet and the wafer. Referring to corresponding FIG. **1**, the upper plan view depicts a metal foil sheet **102** placed over an underlying wafer **104** (shown as dashed lines). The lower cross-sectional view (taken along the a-a' axis of the upper plan view) depicts the metal foil sheet **102** as attached to the metallized surface **106** of the wafer **104**. The underlying wafer **104** is supported by a first support **108** which, in one embodiment, may be a first chuck.

In an embodiment, the metal foil sheet **102** is attached to the metallized surface **106** of the wafer **104** by first fitting-up the metal foil sheet with the metallized surface **106** of the wafer. Subsequent to the fitting-up, the metal foil sheet **102** is adhered to the metallized surface **106** of the wafer **104** by laser welding or thermal compression. In one such embodiment, the metallized surface of the wafer **104** includes alternating N-type and P-type semiconductor regions and a plurality of metal seed material regions on each of the alternating N-type and P-type semiconductor regions, as is described in greater detail below in association with FIGS. **13**A and **13**B. In that embodiment, fitting-up the metal foil sheet **102** involves forming electrical contacts between the metal foil sheet **102** and the plurality of metal seed material regions.

In an embodiment, the metal foil sheet **102** is an aluminum (Al) foil having a thickness approximately in the range of 5-100 microns. In one embodiment, the Al foil is an aluminum alloy foil including aluminum and a second element such as, but not limited to, copper, manganese, silicon, magnesium, zinc, tin, lithium, or combinations thereof. In one embodiment, the Al foil is a temper grade foil such as, but not limited to, F-grade (as fabricated), **0**-grade (full soft), H-grade (strain hardened) or T-grade (heat treated). In one embodiment, the aluminum foil is an anodized aluminum foil.

Referring to operation **704** of flowchart **700**, subsequent to attaching the metal foil sheet **102**, the method involves laser scribing a portion of the metal foil sheet from above to form a groove in the metal foil sheet. Referring to corresponding FIG. **2**A (and as referencing FIG. **1**), in a first example, the wafer **104** has a perimeter, and the metal foil sheet **102** is laser scribed to form a groove **202**A in alignment with the perimeter of the wafer (perimeter shown as dashed line in the plan view FIG. **1**, and laser groove shown as solid line in the plan view of FIG. **2**A). Thus, referring to the cross-sectional view of FIG. **2**A (taken along the b-b' axis), in a first embodiment, the laser scribing provides grooves **202**A in alignment with the edges of the wafer **104**.

Referring to corresponding FIG. **2**B, in a second example, the wafer **104** has a perimeter, and the metal foil sheet **102** is laser scribed to form a groove **202**B inside of (i.e., within) the perimeter of the wafer **104** (perimeter shown as dashed line, and laser groove shown as solid line, in the plan view FIG. **2**B). Thus, referring to the cross-sectional view of FIG. **2**B (taken along the c-c' axis), in a second embodiment, the laser scribing provides grooves **202**B within or inside of the edges of the wafer **104**.

Referring to corresponding FIG. **2**C, in a third example, the wafer **104** has a perimeter, and the metal foil sheet **102** is laser scribed to form a groove **202**C outside of the perimeter of the wafer **104** (perimeter shown as dashed line, and laser groove shown as solid line, in the plan view FIG. **2**C). Thus, referring to the cross-sectional view of FIG. **2**C (taken along the d-d' axis), in a third embodiment, the laser scribing provides grooves **202**C outside of the edges of the wafer **104**.

Referring to corresponding FIG. **2**D, in a fourth example, the wafer **104** has a perimeter, and the metal foil sheet **102** is laser scribed to form a groove **202**D including grooves both outside of the perimeter of the wafer **104** and grooves in alignment with the perimeter of the wafer **104** (portion of perimeter shown as dashed line, and laser groove shown as solid line, in the plan view FIG. **2**D). Thus, in a fourth embodiment, the laser scribing provides groove **202**D which is made up of grooves outside of some of the edges of the wafer **104** and of grooves in alignment with other of the edges of the wafer **104**.

Referring to corresponding FIG. **2**E, in a fifth example, the wafer **104** has a perimeter, and the metal foil sheet **102** is laser scribed to form a groove **202**E including grooves both outside of the perimeter of the wafer **104** and grooves inside of the perimeter of the wafer **104** (perimeter shown as dashed line, and laser groove shown as solid line, in the plan view FIG. **2**E). Thus, in a fifth embodiment, the laser scribing provides groove **202**E which is made up of grooves outside of some of the edges of the wafer **104** and of grooves inside of other of the edges of the wafer **104**.

In an embodiment, referring collectively to FIGS. **2**A-**2**E, laser scribing the metal foil sheet **102** to form a groove (generally referred to as groove **202**) in the metal foil sheet **102** involves forming the groove **202** to a depth approximately in the range of 80-95% of the thickness of the metal foil sheet **102**. In an exemplary embodiment, the metal foil sheet **102** has a thickness of approximately 50 microns, and the grooves **202** are formed to a depth of approximately 45 microns to leave approximately 5 microns of thickness of the metal foil sheet **102** remaining. In an embodiment, the laser scribing further involves forming grooves in the metal foil sheet **102** at locations corresponding to regions between metal seed material regions on the surface of the wafer **102**, as is described in greater detail below in association with FIGS. **13**A and **13**B.

Referring to operation **706** of flowchart **700**, subsequent to laser scribing the metal foil sheet, the method involves rotating the unified pairing of the metal foil sheet and the wafer to provide the metal sheet below the wafer. Referring to corresponding FIG. **3**, the pairing of the metal foil sheet **102** and the wafer **104** is removed from the first support **108** in a first position I. At position I, the metal foil sheet **102** is above the wafer **104**. It is noted that the laser grooves formed in the metal foil sheet at the previous processing operation are labeled as **202** in FIG. **3** to represent any one or combination of the grooves described in association with FIGS. **2**A-**2**E.

Referring again to FIG. **3**, the pairing of the metal foil sheet **102** and the wafer **104** is rotated to a second position II. At position II, the metal foil sheet **102** is below the wafer **104**.

Referring to operation **708** of flowchart **700**, subsequent to the rotating, the method involves placing the unified pairing of the metal foil sheet and the wafer on a chuck with the metal sheet below the wafer. Referring to corresponding FIGS. **3** and **4**, the pairing of the metal foil sheet **102** and the wafer **104** in the second position II is coupled to a chuck **300**. In an embodiment, the pairing of the metal foil sheet **102** and the wafer **104** is held on the chuck **300** by clamping or by vacuum suction. In the latter embodiment, vacuum suction may be achieved using vacuum holes or ports **302** formed in the chuck **300** and opening to the surface of the chuck **300**, as is depicted in FIGS. **3** and **4**. In an embodiment, the chuck **300** is a different support device than the first support **108** described in association with FIGS. **1** and **2**A-**2**E. However, in other embodiments, the chuck **300** is the same support device as the first support **108**.

Referring to operation **710** of flowchart **700**, the method involves tearing the metal foil sheet at least along the groove to trim the metal foil sheet and to leave remaining a metal foil piece electrically connected to the metallized surface of the wafer. Referring to corresponding FIGS. **4** and **5**, the portions of the metal foil sheet **102** that are outside of the laser grooves **202** are gripped and pulled substantially along directions **402** to tear the metal foil sheet at regions **404** (e.g., in alignment with the laser grooves **202**).

Upon tearing and removal of the portions of the metal foil sheet **102** outside of the laser grooves **202**, only the portion **102'** of the metal foil sheet **102** that is inside of the laser grooves **202** remains. That is, the metal foil sheet **102** is torn at locations **202** to ultimately provide a metal foil piece **102'** attached to the metallized surface **106** of the wafer **104**, as is depicted in FIG. **5**. Referring to FIG. **6**, subsequent to tearing the metal foil sheet **102** for trimming, the pairing of the metal foil piece **102'** and the wafer **104** is removed from the chuck **300**.

In another aspect, a metal foil sheet **102** laser scribed to form grooves that outside of the perimeter of the wafer may be further laser scribed to form complementary grooves to assist with the foil trim process based on tearing. As an example, FIGS. **8**A and **8**B illustrate cross-sectional views of various stages in the fabrication of a solar cell using foil-based metallization, in accordance with another embodiment of the present disclosure.

Referring to FIG. **8**A, upon rotating the wafer **104** and metal foil sheet **102** pairing in order to provide the metal foil sheet **102** below the wafer **104**, additional laser scribing may be performed to form grooves **802**. In one such embodiment, the grooves **802** are formed complementary to grooves **202**C formed outside of the perimeter of the wafer **104**, as is depicted in FIG. **8**A. Referring to FIGS. **8**A and **8**B, the fabrication of such complementary grooves in the metal foil sheet **102** may aid with the tearing/trimming of the metal foil sheet **102**. It is to be appreciated that the fabrication of complementary grooves may also be performed for scribe lines having only a portion of the groove outside of the perimeter of the wafer **102**, e.g., partial complementary grooving may be performed for scenarios such as those described in association with FIGS. **2**D and **2**E. In any case, referring to FIG. **8**B, solar cell fabrication processing which retains at least a portion of the metal foil sheet **102** as an overhang portion may benefit from complementary groove formation. In yet another embodiment, the same scenarios having at least a portion of the groove outside of the perimeter of the wafer may instead be initially laser scribed entirely through the metal foil sheet to form breaks at those locations during the preliminary laser scribing process.

In a second aspect, a foil trim approach is applied with a solar cell and foil pairing oriented wafer-side down on a chuck. Consistent with the first aspect, FIGS. **9**A-**9**D illustrate cross-sectional views of various stages in the fabrication of a solar cell using foil-based metallization, in accordance with another embodiment of the present disclosure.

Referring to FIGS. **9**A and **9**B, a laser grooved **202** metal foil sheet **102** and wafer **104** pairing is placed on a chuck **300** while in position I instead of in position II (referencing the positions described in association with FIG. **3**). Referring to FIGS. **9**C and **9**D, the portions of the metal foil sheet **102** that are outside of the laser grooves **202** are gripped and pulled substantially along directions **402** to tear the metal foil sheet at regions **404** (e.g., in alignment with the laser grooves **202**). It is to be appreciated that, although not depicted in FIG. **9**B, in the case that vacuum suction is used to hold the pairing to the chuck **300**, the metal foil sheet **102** may be pulled to the top surface of the chuck, at least somewhat conformal to the wafer **104**.

Upon tearing and removal of the portions of the metal foil sheet **102** outside of the laser grooves **202**, only the portion **102'** of the metal foil sheet **102** that is inside of the laser grooves **202** remains. That is, the metal foil sheet **102** is torn at locations **202** to ultimately provide a metal foil piece **102'** attached to the metallized surface **106** of the wafer **104**, as is depicted in FIG. **9**D. Also shown in FIG. **9**D, subsequent to tearing the metal foil sheet **102** for trimming, the pairing of the metal foil piece **102'** and the wafer **104** is removed from the chuck **300**.

Referring again to FIG. **9**C, in an embodiment, a platen **902** is pressed down in direction **904** onto the metal foil sheet **102**. In one such embodiment, the platen **902** is pressed down onto the metal foil sheet **102** to reduce mechanical stress on the metallized surface **106** of the wafer **104** during the tearing of the metal foil sheet **102**.

Perhaps more generally, referring to both approaches described above, FIG. **10** is a flowchart **1000** listing operations in a method of fabricating a solar cell, in accordance with an embodiment of the present disclosure.

Referring to operation **1002** of flowchart **1000**, a method of fabricating a solar cell involves laser scribing a metal foil sheet **102** attached to a metallized surface **106** of a wafer **104** to form a groove in the metal foil sheet **102**. At operation **1004**, subsequent to the laser scribing, the method further involves holding the metal foil sheet **102** or the wafer on a chuck **300** by vacuum suction. At operation **1006**, while holding the metal foil sheet **102** or the wafer **104** on the chuck **300**, the method further involves tearing the metal foil sheet **102** at least along the groove to trim the metal foil sheet **102** and to leave remaining a metal foil piece **102'** electrically connected to the metallized surface **106** of the wafer **104**. In one embodiment, the metal foil sheet **102** of the metal foil sheet **102** and wafer **104** pairing is held on the chuck **300**, as described in association with FIGS. **1**, **2**A-**2**E and **3**-**7**. In another embodiment, the wafer **104** of the metal foil sheet **102** and wafer **104** pairing is held on the chuck **300**, as described in association with FIGS. **9**A-**9**E.

In another aspect, new solar cell architectures are achievable using one or more of the above described foil trim approaches. In a first example, FIG. **11** illustrates plan and cross-sectional views of a solar cell having foil-based metallization, in accordance with an embodiment of the present disclosure.

Referring to FIG. **11**, a solar cell is formed based on a metal foil process and laser grooving described in association with FIG. **2**D. In particular, a remaining metal foil piece **102'** is electrically connected to an underlying wafer **104** (a portion of the perimeter of which is shown by the dashed lines in the plan view of FIG. **11**). The metal foil piece **102'** has a perimeter with a first portion in alignment with a first portion of the perimeter of the wafer **104** (as seen in the cross-sectional view taken along the f-f' axis). The perimeter of the metal foil piece **102'** also has a second portion overhanging a second portion of the perimeter of the wafer **104** (as seen in the cross-sectional view taken along the g-g' axis).

In a second example, FIG. **12** illustrates plan and cross-sectional views of another solar cell having foil-based metallization, in accordance with another embodiment of the present disclosure.

Referring to FIG. **12**, a solar cell is formed based on a metal foil process and laser grooving described in association with FIG. **2**E. In particular, a remaining metal foil piece **102'** is electrically connected to an underlying wafer **104** (a portion of the perimeter of which is shown by the dashed lines, and a portion of which is shown in solid lines, in the plan view of FIG. **12**). The metal foil piece **102'** has a perimeter with a first portion within a first portion of the perimeter of the wafer **104** (as seen in the cross-sectional view taken along the h-h' axis). The perimeter of the metal foil piece **102'** also has a second portion overhanging a second portion of the perimeter of the wafer **104** (as seen in the cross-sectional view taken along the i-i' axis).

As described briefly above, initial patterning of the metal foil in contact with emitter regions of a solar cell may be performed during the lasing operation implemented for foil trim. As an example, FIGS. **13**A and **13**B illustrate cross-sectional views of various stages in the fabrication of a solar cell using foil-based metallization, in accordance with another embodiment of the present disclosure.

Referring to FIG. **13**A, a plurality of alternating N-type and P-type semiconductor regions are formed above a substrate. In particular, a substrate **1300** has disposed there above N-type semiconductor regions **1304** and P-type semiconductor regions **1306** disposed on a thin dielectric material **1302** as an intervening material between the N-type semiconductor regions **1304** or P-type semiconductor regions **1306**, respectively, and the substrate **1300**. The substrate **1300** has a light-receiving surface **1301** opposite a back surface above which the N-type semiconductor regions **1304** and P-type semiconductor regions **1306** are formed.

In an embodiment, the substrate **1300** is a monocrystalline silicon substrate, such as a bulk single crystalline N-type doped silicon substrate. It is to be appreciated, however, that substrate **1300** may be a layer, such as a multi-crystalline silicon layer, disposed on a global solar cell substrate. In an embodiment, the thin dielectric layer **1302** is a tunneling silicon oxide layer having a thickness of approximately 2 nanometers or less. In one such embodiment, the term "tunneling dielectric layer" refers to a very thin dielectric layer, through which electrical conduction can be achieved. The conduction may be due to quantum tunneling and/or the presence of small regions of direct physical connection through thin spots in the dielectric layer. In one embodiment, the tunneling dielectric layer is or includes a thin silicon oxide layer.

In an embodiment, the alternating N-type and P-type semiconductor regions **1304** and **1306**, respectively, are formed from polycrystalline silicon formed by, e.g., using a plasma-enhanced chemical vapor deposition (PECVD) process. In one such embodiment, the N-type polycrystalline silicon emitter regions **1304** are doped with an N-type impurity, such as phosphorus. The P-type polycrystalline silicon emitter regions **1306** are doped with a P-type impurity, such as boron. As is depicted in FIG. **13**A, the alternating N-type and P-type semiconductor regions **1304** and **1306** may have trenches **1308** formed there between, the trenches **1308** extending partially into the substrate **1300**. Additionally, in one embodiment, a bottom anti-reflective coating (BARC) material **1310** or other protective layer (such as a layer amorphous silicon) is formed on the alternating N-type and P-type semiconductor regions **1304** and **1306**, as is depicted in FIG. **13**A.

In an embodiment, the light receiving surface **1301** is a texturized light-receiving surface, as is depicted in FIG. **13**A. In one embodiment, a hydroxide-based wet etchant is employed to texturize the light receiving surface **1301** of the substrate **1300** and, possibly, the trench **1308** surfaces as is also depicted in FIG. **13**A. It is to be appreciated that the timing of the texturizing of the light receiving surface may vary. For example, the texturizing may be performed before or after the formation of the thin dielectric layer **3102**. In an embodiment, a texturized surface may be one which has a regular or an irregular shaped surface for scattering incoming light, decreasing the amount of light reflected off of the light receiving surface **1301** of the solar cell. Referring again to FIG. **13**A, additional embodiments can include formation of a passivation and/or anti-reflective coating (ARC) layers (shown collectively as layer **1312**) on the light-receiving surface **1301**. It is to be appreciated that the timing of the formation of passivation and/or ARC layers may also vary.

Referring again to FIG. **13**A, a plurality of metal seed material regions **1314** is formed to provide a metal seed material region on each of the alternating N-type and P-type semiconductor regions **1304** and **1306**, respectively. The metal seed material regions **1314** make direct contact to the alternating N-type and P-type semiconductor regions **1304** and **1306**. In an embodiment, the metal seed regions **1314** are aluminum regions. In one such embodiment, the aluminum regions each have a thickness approximately in the range of 0.3 to 20 microns and include aluminum in an amount greater than approximately 97% and silicon in an amount approximately in the range of 0-2%. In other embodiments, the metal seed regions **1314** include a metal such as, but not limited to, nickel, silver, cobalt or tungsten. Optionally, a protection layer may be included on the plurality of metal seed material regions **1314**. In a particular embodiment, an insulating layer **1316** is formed on the plurality of metal seed material regions **1314**. In an embodiment, the insulating layer **1316** is a silicon nitride or silicon oxynitride material layer. In another embodiment, in place of the metal seed regions **1314**, a blanket metal seed layer is used that is not patterned at this stage of processing. In that embodiment, the blanket metal seed layer may be patterned in a subsequent etching process, such as a hydroxide-based wet etching process.

Referring again to FIG. **13**A, a metal foil **1318** is adhered to the alternating N-type and P-type semiconductor regions by directly coupling portions of the metal foil **1318** with a corresponding portion of each of the metal seed material regions **1314**. In one such embodiment, the direct coupling of portions of the metal foil **1318** with a corresponding portion of each of the metal seed material regions **1314** involves forming a metal weld **1320** at each of such locations, as is depicted in FIG. **13**A.

In an embodiment, the metal foil **1318** is an aluminum (Al) foil having a thickness approximately in the range of 5-100 microns. In one embodiment, the Al foil is an aluminum alloy foil including aluminum and second element such as, but not limited to, copper, manganese, silicon, magnesium, zinc, tin, lithium, or combinations thereof. In one embodiment, the Al foil is a temper grade foil such as, but not limited to, F-grade (as fabricated), **0**-grade (full soft), H-grade (strain hardened) or T-grade (heat treated). In one embodiment, the aluminum foil is an anodized aluminum foil. In an embodiment, the metal foil **1318** is adhered directly to the plurality of metal seed material regions **1314** by using a technique such as, but not limited to, a laser welding process, a thermal compression process or an ultrasonic bonding process. In an embodiment, the optional insulating layer **1316** is included, and adhering the metal foil **1318** to the plurality of metal seed material regions **1314** involves breaking through regions of the insulating layer **1316**, as is depicted in FIG. **13**A.

It is to be appreciated that, in accordance with another embodiment of the present disclosure, a seedless approach may be implemented. In such an approach, metal seed material regions **1314** are not formed, and the metal foil **1318** is adhered directly to the material of the alternating N-type and P-type semiconductor regions **1304** and **1306**. For example, in one embodiment, the metal foil **1318** is adhered directly to alternating N-type and P-type polycrystalline silicon regions.

FIG. **13**B illustrates the structure of FIG. **13**A following formation of laser grooves in the metal foil. Referring to FIG. **13**B, the metal foil **1318** is laser ablated through only a portion of the metal foil **1318** at regions corresponding to locations between the alternating N-type and P-type semiconductor regions **1304** and **1306**, e.g., above trench **1308** locations as is depicted in FIG. **13**B. The laser ablating forms grooves **1330** that extend partially into, but not entirely through, the metal foil **1318**. In an embodiment, forming laser grooves **1330** involves laser ablating a thickness of the metal foil **1318** approximately in the range of 80-99% of an entire thickness of the metal foil **1318**. That is, in one embodiment, it is critical that the lower portion of the metal foil **1318** is not penetrated, such that metal foil **1318** protects the underlying emitter structures.

In an embodiment, the structure of FIG. **13**B may also be subjected to a metal foil trim process, such as one of the processes described above. In one such embodiment, initial laser grooving for one of the above described foil trim approaches is performed in a same laser process used to perform the laser grooving to form grooves **1330**. Following foil trim, the grooves **1330** of FIG. **13**B may then be used to isolate conductive regions **1340** as metallization structure for the underlying emitter regions.

In a first exemplary embodiment, following a foil trim process, the remaining metal foil **1318** is subsequently anodized at exposed surfaces thereof to isolate regions **1340** of the remaining metal foil **1318** corresponding to the alternating N-type and P-type semiconductor regions **1304** and **1306**. In particular, the exposed surfaces of the metal foil **1318**, including the surfaces of the grooves **1330**, are anodized to form an oxide coating. At locations corresponding to the alternating N-type and P-type semiconductor regions **1304** and **1306**, e.g., in the grooves **1330** at locations above the trenches **1308**, the entire remaining thickness of the metal foil **1318** is anodized there through to isolate regions **1340** of metal foil **1318** remaining above each of the N-type and P-type semiconductor regions **1304** and **1306**.

In a second exemplary embodiment, following a foil trim process, instead of anodizing the metal foil **1318** to isolate portions of the metal foil **1318**, the patterned metal foil **1318** is etched to isolate portions **1340** of the metal foil **1318**. In one such embodiment, the structure of FIG. **13**B (as remaining following a foil trim process) is exposed to a wet etchant. Although the wet etchant etches all exposed portions of the metal foil **1318**, a carefully timed etch process is used to break through the bottoms of the laser grooves **1330** without significantly reducing the thickness of the non-grooved regions **1340** of the metal foil **1318**. In a particular embodiment, a hydroxide based etchant is used, such as, but not limited to, potassium hydroxide (KOH) or tetramethylammonium hydroxide (TMAH). In either of the first or the second above described embodiments, the break through process of the laser grooves forms breaks in the metal foil piece that remains attached to the underlying wafer.

Coupling of a metal foil with underlying emitter regions of a solar cell (or metal seed regions on the emitter regions) need not require direct coupling of all contact points of the metal foil and the solar cell. As an example, FIGS. **14**A and **14**B illustrate angled views of various stages in the fabrication of a solar cell using foil-based metallization, in accordance with another embodiment of the present disclosure.

Referring to FIG. **14**A, a metal foil **1418** is fit-up with a wafer **1400** having a plurality of emitter regions **1414** (which may include metal seed regions) disposed thereon. Referring to FIG. **14**B, laser welding is performed in only certain location in order to generate weld spots **1420** adhering the foil **1418** to the plurality of emitter regions **1414**. The structure of FIG. **14**B may then be subjected to a metal foil trim process, such as one of the processes described above. Furthermore, the structure of FIG. **14**B may also be subjected to a contact metallization patterning process, such as the process described in association with FIGS. **13**A and **13**B.

Although certain materials are described specifically with reference to above described embodiments, some materials may be readily substituted with others with other such embodiments remaining within the spirit and scope of embodiments of the present disclosure. For example, in an embodiment, a different material substrate, such as a group III-V material substrate, can be used instead of a silicon substrate. Additionally, although reference is made significantly to back contact solar cell arrangements, it is to be appreciated that approaches described herein may have application to front contact solar cells as well. In other embodiments, the above described approaches can be applicable to manufacturing of other than solar cells. For example, manufacturing of light emitting diode (LEDs) may benefit from approaches described herein.

Thus, foil trim approaches for foil-based metallization of solar cells and the resulting solar cells have been disclosed.

Although specific embodiments have been described above, these embodiments are not intended to limit the scope of the present disclosure, even where only a single embodiment is described with respect to a particular feature. Examples of features provided in the disclosure are intended to be illustrative rather than restrictive unless stated otherwise. The above description is intended to cover such alternatives, modifications, and equivalents as would be apparent to a person skilled in the art having the benefit of this disclosure.

The scope of the present disclosure includes any feature or combination of features disclosed herein (either explicitly or implicitly), or any generalization thereof, whether or not it mitigates any or all of the problems addressed herein. Accordingly, new claims may be formulated during prosecution of this application (or an application claiming priority thereto) to any such combination of features. In particular, with reference to the appended claims, features from dependent claims may be combined with those of the independent claims and features from respective independent claims may be combined in any appropriate manner and not merely in the specific combinations enumerated in the appended claims.

What is claimed is:

1. A method of fabricating a solar cell, the method comprising:

attaching a metal foil sheet to a metallized surface of an underlying supported wafer to provide a unified pairing of the metal foil sheet and the wafer;

subsequent to attaching the metal foil sheet, laser scribing a portion of the metal foil sheet from above to form a groove in the metal foil sheet;

subsequent to laser scribing the metal foil sheet, rotating the unified pairing of the metal foil sheet and the wafer to provide the metal sheet below the wafer;

subsequent to the rotating, placing the unified pairing of the metal foil sheet and the wafer on a chuck with the metal sheet below the wafer; and

tearing the metal foil sheet at least along the groove to trim the metal foil sheet and to leave remaining a metal foil piece electrically connected to the metallized surface of the wafer.

2. The method of claim **1**, wherein placing the unified pairing of the metal foil sheet and the wafer on the chuck comprises further comprises holding the unified pairing on the chuck by vacuum suction or by clamping.

3. The method of claim **1**, wherein the wafer has a perimeter, and wherein laser scribing the portion of the metal foil sheet forms the groove in alignment with or within a portion of the perimeter of the wafer.

4. The method of claim **3**, wherein laser scribing the portion of the metal foil sheet further forms a second groove outside of a portion of the perimeter of the wafer.

5. The method of claim **4**, further comprising:

further laser scribing the second groove to form a cut in a portion of the metal foil sheet.

6. The method of claim **4**, further comprising:

subsequent to rotating the unified pairing of the metal foil sheet and the wafer and prior to tearing the metal foil sheet, laser scribing the metal foil sheet in alignment with the second groove to form a complementary groove in the metal foil sheet.

7. The method of claim **1**, wherein the wafer has a perimeter, and wherein laser scribing the portion of the metal foil sheet forms the groove outside of a portion of the perimeter of the wafer.

8. The method of claim **7**, further comprising:

further laser scribing the groove to form a cut in a portion of the metal foil sheet.

9. The method of claim **7**, further comprising:

subsequent to rotating the unified pairing of the metal foil sheet and the wafer and prior to tearing the metal foil sheet, laser scribing the metal foil sheet in alignment with the groove to form a complementary groove in the metal foil sheet.

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